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5th Report of the Royal Commn upon Sewage Disposal

VICTORIA R.

Victoria, by the Grace of God, of the United Kingdom of Great Britain and Ireland Queen, Defender of the Faith: To Our Right Trusty and Right Well-beloved Cousin, Walter Stafford, Earl of Iddesleigh, Companion of Our Most Honourable Order of the Bath; Our Trusty and Well-beloved Sir Richard Thorne Thorne, Knight Commander of Our Most Honourable Order of the Bath, Medical Officer of the Local Government Board; Our Trusty and Well-beloved Constantine Phipps Carey, Esquire, Lieutenant-Colonel and Honorary Major-General on the Retired List of Our Army; Our Trusty and Well-beloved Charles Philip Cotton, Esquire; Our Trusty and Well-beloved Michael Foster, Esquire, Master of Arts, Professor of Physiology in Our University of Cambridge; Our Trusty and Well-beloved Thomas Walter Harding, Esquire, Retired Lieutenant-Colonel of Our Auxiliary Forces, with Honorary Rank of Colonel; Our Trusty and Well-beloved Thomas William Killick, Esquire; Our Trusty and Well-beloved William Ramsay, Esquire, Professor of Chemistry, University College, London; and Our Trusty and Well-beloved James Burn Russell, Esquire, Doctor of Medicine, Master of Surgery: Greeting!

Whereas We have deemed it expedient that a Commission should forthwith issue to inquire and report:

1. (1) What method or methods of treating and disposing of sewage (including any liquid from any factory, or manufacturing process) may properly be adopted, consistently with due regard for the requirements of the existing law, for the protection of the public health, and for the economical and efficient discharge of the duties of local authorities; and

   (2) If more than one method may be so adopted, by what rules, in relation to the nature or volume of sewage, or the population to be served, or other varying circumstances or requirements, should the particular method of treatment and disposal to be adopted be determined; and

2. To make any recommendations which may be deemed desirable with reference to the treatment and disposal of sewage;

Now know ye, that We, reposing great trust and confidence in your knowledge and ability, have authorised and appointed, and do by these Presents authorise and appoint, you, the said Walter Stafford, Earl of Iddesleigh, Sir Richard Thorne Thorne, Constantine Phipps Carey, Charles Philip Cotton, Michael Foster, Thomas Walter Harding, Thomas William Killick, William Ramsay, and James Burn Russell to be Our Commissioners for the purposes of the said Inquiry.

And, for the better effecting the purposes of this, Our Commission, We do by these Presents give and grant unto you, or any three or more of you, full power to call before you such persons as you shall judge likely to afford you any information upon the subject of this Our Commission; and also to call for, have access to, and examine all such books, documents, registers, and records as may afford you the fullest information on the subject, and to inquire of and concerning the premises by all other lawful ways and means whatsoever.

And We do by these Presents authorise and empower you, or any three or more of you, to visit and personally inspect such places as you may deem it expedient so to inspect for the more effectual carrying out of the purposes aforesaid.

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And We do further by these Presents will and ordain that this Our Commission shall continue in full force and virtue, and that you, Our said Commissioners, or any three or more of you, may from time to time proceed in the execution thereof, and of every matter and thing therein contained, although the same be not continued from time to time by adjournment.

And We do further ordain that you, or any three or more of you, have liberty to report your proceedings under this Our Commission from time to time, if you shall judge it expedient so to do.

And Our further Will and Pleasure is that you do, with as little delay as possible, report to Us, under your hands and seals, or under the hands and seals of any three or more of you, your opinion upon the matters herein submitted for your consideration.

And for the purpose of aiding you in such matters, We hereby appoint Our Trusty and Well-beloved Frederick James Willis, Esquire, to be Secretary to this Our Commission.

Given at Our Court at St. James's, the Seventh day of May, One thousand eight hundred and ninety-eight, in the Sixty-first Year of Our Reign.

By Her Majesty's Command,
(Signed) M. W. Ridley.

William Henry Power, Esq., F.R.S.,
To be a Member of the Royal Commission on Sewage Disposal.

VICTORIA R.

Victoria, by the Grace of God, of the United Kingdom of Great Britain and Ireland Queen, Defender of the Faith: To Our Right Trusty and Well-beloved William Henry Power, Esquire, Fellow of the Royal Society, Medical Officer of the Local Government Board: Greeting!

Whereas We did, by Warrant under Our Royal Sign Manual, bearing date the Seventh day of May, One thousand eight hundred and ninety-eight, appoint Our Right Trusty and Right Well-beloved cousin Walter Stafford, Earl of Iddesleigh, Companion of Our Most Honourable Order of the Bath, together with the several Gentlemen therein mentioned, or any three or more of them, to inquire into the treatment and disposal of sewage.

And whereas One of the Commissioners so appointed, namely, Sir Richard Thorne Thorne, has since deceased.

Now know Ye, that We, reposing great confidence in you, do, by these Presents, appoint you, the said William Henry Power, to be one of Our Commissioners for the purpose aforesaid, in the room of the said Sir Richard Thorne Thorne, deceased, in addition to, and together with, the other Commissioners whom we have already appointed.

Given at our Court at Saint James's, the Seventh day of February, One thousand nine hundred, in the Sixty-third Year of Our Reign.

By Her Majesty's Command,
(Signed) M. W. Ridley.

Whitehall, March 18th, 1901.

The King has been pleased to issue a Commission, under His Majesty's Royal Sign Manual, to the following effect:—

EDWARD R.

Edward the Seventh, by the Grace of God, of the United Kingdom of Great Britain and Ireland King, Defender of the Faith, to all to whom these Presents shall come, Greeting!

Whereas it pleased Her late Majesty from time to time to issue Royal Commissions of Inquiry for various purposes therein specified:

And whereas in the case of certain of these Commissions, namely, those known as—

The Historical Manuscripts Commission;
The Horse Breeding Commission;
The Local Taxation Commission;
The Port of London Commission;
The Salmon Fisheries Commission; and
The Sewage Disposal Commission;

the Commissioners appointed by Her late Majesty, or such of them as were then acting as Commissioners, were, at the late demise of the Crown, still engaged upon the business entrusted to them:

And whereas We deem it expedient that the said Commissioners should continue their labours in connection with the said enquiries notwithstanding the late demise of the Crown:

Now know Ye, that We, reposing great trust and confidence in the zeal, discretion, and ability of the present members of each of the said Commissions, do by these Presents authorise them to continue their labours, and do hereby in every essential particular ratify and confirm the terms of the said several Commissions.

And We do further ordain that the said Commissions do report to Us under their hands and seals, or under the hands and seals of such of their number as may be specified in the said Commissions respectively, their opinion upon the matters presented for their consideration; and that any proceedings which they or any of them may have taken under and in pursuance of the said Commissions since the late demise of the Crown, and before the issue of these Presents shall be deemed and adjudged to have been taken under and in virtue of this Our Commission.

Given at Our Court at Saint James's, the fourth day of March, One thousand nine hundred and one, in the First Year of Our Reign.

By His Majesty's Command,
(Signed) Chas. T. Ritchie.

THOMAS JOSEPH STAFFORD, F.R.C.S.I.,
To be a Member of the Royal Commission on Sewage Disposal.

EDWARD R.

Edward the Seventh, by the Grace of God, of the United Kingdom of Great Britain and Ireland and of the British Dominions beyond the Seas King, Defender of the Faith, To Our Trusty and Well-beloved Thomas Joseph Stafford, Esquire, Fellow of the Royal College of Surgeons of Ireland, Medical Commissioner of the Local Government Board for Ireland: Greeting!

Whereas Her late Majesty Queen Victoria did by Warrant under the Royal Sign Manual bearing date the Seventh Day of May One thousand eight hundred and ninety-eight, appoint Our Right Trusty and Right Well-beloved Cousin, Walter Stafford, Earl of Iddesleigh, Companion of Our Most Honourable Order of the Bath, together with the several Gentlemen therein mentioned, to be Commissioners to inquire into the treatment and disposal of Sewage.

And whereas one of the Commissioners so appointed, namely, Our Trusty and Well-beloved Charles Philip Cotton, Esquire, hath humbly tendered unto Us his resignation of his appointment as one of the said Commissioners:

Now know Ye, that We, reposing great confidence in you, do by these Presents appoint you, the said Thomas Joseph Stafford, to be one of Our Commissioners for the purpose aforesaid, in the room of the said Charles Philip Cotton, resigned, in addition to and together with the present Members of the Commission.

Given at Our Court at Saint James's, the Seventh day of May, One thousand nine hundred and two, in the Second Year of Our Reign.

By His Majesty's Command.
(Signed) CHAS. T. RITCHIE.

REGINALD ARTHUR TATTON, ESQUIRE,
To be a Member of the Royal Commission on Sewage Disposal.

EDWARD R. & I.

Edward the Seventh, by the Grace of God, of the United Kingdom of Great Britain and Ireland and of the British Dominions beyond the Seas King, Defender of the Faith, To Our Trusty and Well-beloved Reginald Arthur Tatton, Esquire, Greeting!

Whereas Her late Majesty Queen Victoria did by Warrant under the Royal Sign Manual bearing date the Seventh Day of May, One thousand eight hundred and ninety-eight, appoint Commissioners to inquire into the treatment and disposal of Sewage.

And whereas a vacancy has been caused in the body of the Commissioners appointed as aforesaid by the death of Major-General Constantine Phipps Carey, C.B.

Now know Ye, that We, reposing great confidence in you, do by these Presents appoint you, the said Reginald Arthur Tatton, to be one of Our Commissioners for the purpose aforesaid, in the room of the said Constantine Phipps Carey, deceased, in addition to and together with the present Members of the Commission.

Given at Our Court at Saint James's, the Seventh day of January, One thousand nine hundred and seven, in the Sixth Year of Our Reign.

By His Majesty's Command.
(Signed) H. J. GLADSTONE.

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REPORT.

TO THE KING'S MOST EXCELLENT MAJESTY:

We, the Commissioners appointed to inquire and report:—

I.—(1) What method or methods of treating and disposing of sewage (including any liquids from any factory or manufacturing process) may properly be adopted, consistently with due regard for the requirements of the existing law, for the protection of public health, and for the economical and efficient discharge of the duties of local authorities; and

(2) If more than one method may be so adopted, by what rules, in relation to the nature or volume of sewage, or the population to be served, or other varying circumstances or requirements, the particular method of treatment and disposal to be adopted be determined; and

II.—To make any recommendations which may be deemed desirable with reference to the treatment and disposal of sewage,

humbly report as follows:—

INTRODUCTION.

1. In this our fifth Report, we propose chiefly to deal with the relative merits of the various methods which are available for the purification of sewage of towns. In a subsequent report we shall deal with the various methods which are available for the purification of trade effluents, when not mixed with sewage.

2. The subject of sewage disposal has been inquired into by the following Committees and Commissions:—

1857. Commission to inquire into the best mode of distributing the sewage of towns and applying it to beneficial and profitable uses.

1862. Select Committee of the House of Commons to inquire into the best means of utilising the sewage of cities and towns of England, with a view to the reduction of local taxation and the benefit of agriculture.

1864. Select Committee of the House of Commons to inquire into any plans for dealing with the sewage of the Metropolis and other large towns, with a view to its utilisation for agricultural purposes.

1865. First Royal Commission to inquire into the best means of preventing the pollution of rivers.

1868. Second Royal Commission to inquire into the best means of preventing the pollution of rivers.

1869. Royal Commission to inquire into and report upon the operation and administration of the sanitary laws outside the Metropolis.

1875. Committee appointed by the President of the Local Government Board to inquire into the several modes of treating town sewage.

1882. Royal Commission to inquire into and report upon the system under which sewage is discharged into the Thames by the Metropolitan Board of Works, whether any evil effects result therefrom, and in that case what remedies can be applied for remedying or preventing the same.

3. The general conclusion of these bodies has been that sewage could only be properly purified by land treatment; and, as a consequence, it has been usual to require local authorities to adopt land treatment.

During recent years, however, certain methods differing from those which were considered by the earlier Commissions have been evolved, and, in view of the difficulty—or even impossibility—which many local authorities experience in obtaining adequate areas of suitable land at reasonable cost, it was considered desirable that these newer methods should be carefully investigated. This led to the appointment of our Commission.

4. One of the first steps taken by us after our appointment was to seek examples of these newer methods. We visited several places which were suggested to us, but in no case was the whole of the sewage of a town being dealt with; in most of the cases no more than a small and a constant quantity of sewage was being treated by the particular process. Moreover, the number of places in which experiments on anything approaching a practical scale were being carried on was very limited. We learnt, however, that for several towns it was proposed to adopt one or other of these newer processes, and we therefore decided to postpone experimental investigation into their merits until the field for observation was more extended.

5. One of our earliest witnesses, the late Mr. Santo Crimp, an engineer of wide experience, pointed out the danger of basing final conclusions as to a process on the results obtained with experimental plant, and there can be no doubt that inferences so founded must be drawn with caution, especially so when the amount of sewage being dealt with is a fixed quantity each day, and when the experiment does not adequately reproduce the many varying conditions which occur in practice.

Moreover, the weak points in a method of sewage disposal may sometimes only be disclosed after long experience covering a wide range of conditions.

Further, the character of the sewage of different towns varies to so great an extent that it would be unsafe to formulate definite conclusions as to the relative merits of different processes until experience had been gained of their sustained application to different types of sewage.

6. In our first Report we pointed out that at the time of the investigations of the earlier Commissions, the science of bacteriology was in its infancy; those Commissions, indeed, confined themselves almost entirely to a chemical examination of sewage effluents. Since the earlier Commissions reported, a large amount of exact knowledge has been gained concerning the part played by bacteria in various processes of nature and under conditions contrived by man, and it became our duty to study the various questions connected with sewage disposal, not only from a chemical, but also from a bacteriological point of view. This has largely increased our labours.

We have had to initiate and carry out various bacteriological investigations, and apprehending that the work done by earlier Commissions in regard to land treatment did not suffice for our purposes, we have found it necessary to include in our work a systematic and detailed investigation, bacteriological and chemical, of the treatment of sewage on land of various kinds.

PLAN OF WORK.

7. Our investigation has been carried on in the following manner:—

(I) We have held 144 meetings and called before us the following witnesses:—

Name.	Qualification.
Mr. Alfred D. Adrian, C.B.	Assistant Secretary to the Local Government Board (England and Wales).
Mr. A. Murray	Chief Clerk to the Local Government Board (Scotland).
Mr. L. E. H. Deane	Engineering Inspector to the Local Government Board (Ireland).
Mr. R. A. Tatton, M.Inst.C.E.	Chief Inspector to the Mersey and Irwell Joint Committee (1898).
Mr. F. Scudder, F.I.C., F.C.S.	Acting Chemist to the Mersey and Irwell Joint Committee under the supervision of Sir Henry Roscoe, F.R.S.
Mr. W. H. Wilson	Deputy Clerk and Solicitor to the Mersey and Irwell and Ribble Joint Committees.
Mr. W. Naylor, A.M.Inst.C.E., F.C.S.	Chief Inspector of the Ribble Joint Committee (1898).
Mr. Trevor Edwards	Clerk and Solicitor to the West Riding of Yorkshire Rivers Board.
Mr. H. Maclean Wilson, M.D., B.Sc.	Chief Inspector of the West Riding of Yorkshire Rivers Board.
Mr. Theodore Thomson, M.D.	Medical Inspector under the Local Government Board.
Mr. W. Santo Crimp, M.Inst.C.E., F.S.I.	Civil Engineer.
Mr. W. S. Curphey, F.I.C., F.C.S.	H.M. Inspector for Scotland under the Alkali Acts and the Rivers Pollution Prevention Acts.
Mr. Donald Cameron	City Surveyor of Exeter.
Mr. W. J. Dibdin, F.I.C., F.C.S.	Chemist.
Colonel Ducat	Inventor of the "Ducat" filter.
Mr. W. E. Adeney, D.Sc., F.I.C.	Curator and ex-Examiner in Chemistry in the Royal University, Dublin.
Mr. H. Marshall Ward, F.R.S., D.Sc.	Professor of Botany, University of Cambridge.
Dr. G. Sims Woodhead	Director of the Research Laboratories of the Conjoint Board of the Royal College of Physicians (Lond.) and the Royal College of Surgeons (Eng.).
Sir Edward Frankland, K.C.B.	Member of the Commission appointed in 1868 to inquire into the best means of preventing the pollution of rivers.
Mr. W. D. Scott Moncrieff, M.I.M.E.	Engineer.
Mr. J. Garfield, A.M.Inst.C.E.	Engineer in Charge of Sewage Disposal Works at Wolverhampton.
Sir Henry Roscoe, F.R.S., D.C.L., LL.D	Professor of Chemistry in the Owen's College, Victoria University, Manchester, and Scientific Adviser to the Mersey and Irwell Joint Committee.
Mr. Sidney Barwise, M.D. (Lond.), D.P.H. (Camb.)	County Medical Officer of Derbyshire.
Mr. S. Rideal, D.Sc., F.I.C.	Chemist.
Mr. Baldwin Latham, M.Inst.C.E., etc.	Civil Engineer.
Mr. C. J. Whittaker	Chairman of the Accrington and Church Outfall Sewage Works.
Mr. T. Cosham	Representing the Natural Purification Company.
Mr. A. P. Hope, F.C.S.	Representing the "Bacillite" Sewage Purification process.
Mr. H. B. Jagger	Representing the Carbonised Refuse System of Sewage Purification.
Mr. F. Wallis Stoddart, F.I.C., F.C.S.	City Analyst for Bristol.
Mr. W. Brown	Representing the Reeves Chemical Sanitation Company's process.
Mr. W. C. Silar	Representing the "A.B.C." process.
Mr. Douglas Archibald	Representing the "A.B.C." process.
Mr. H. Wollheim	Representing the "Amines" process.
Mr. W. H. Harrison, M.Sc.	Chemist to the Leeds Sewage Committee.
Mr. W. Eason	City Surveyor of Ripon.
Mr. F. Bagshaw	Borough Surveyor of Harrogate.
Mr. Gilbert J. Fowler, D.Sc., F.I.C.	Superintendent and Chemist of the Manchester Corporation Sewage Works.

Name.	Qualification.
Mr. W. J. Newton, A.M.Inst.C.E.	Engineering Adviser to the Accrington and Church Outfall Sewage Board.
Mr. J. Barnes	Superintendent Chemist in Charge of the Accrington and Church Outfall Sewage Works.
Dr. A. C. Houston	Bacteriologist to Commission.
Dr. G. McGowan	Chemist to Commission.
Mr. G. Chatterton, M.Inst.C.E.	Civil Engineer.
Mr. D. Balfour, M.Inst.C.E.	Civil Engineer.
Mr. W. H. Prescott	Borough Engineer of Reigate.
Mr. Frank Candy	Surveyor and Sanitary Engineer of the International Purification Syndicate.
Colonel Harding	Member of the Commission and Chairman of the Leeds Sewerage Committee.
Mr. G. R. Strachan, M.Inst.C.E.	Civil Engineer.
Mr. Alderman H. F. Hibbert	Chairman of the Chorley Sewage Works and member of the Ribble Joint Committee.
Mr. E. G. Mawbey, M.Inst.C.E.	Borough Engineer of Leicester.
Prof E. A. Letts, D.Sc., F.I.C., Ph.D.	Professor of Chemistry at Queen's College, Belfast.
Prof. W. A. Herdman, D.Sc., F.R.S.	University College, Liverpool, and Honorary Director of Scientific Work to the Lancashire and Western Sea Fisheries Committee.
The Hon. T. H. W. Pelham	Assistant Secretary to the Board of Trade.
Mr. J. C. Thresh, M.D., D.Sc., D.Ph., F.I.C.	Medical Officer of Health of the Essex County Council.
Mr. T. E. Hill, M.D.	County Medical Officer, Durham.
Mr. G. V. Poore, M.D., F.R.C.P.	Professor of Medicine at University College, London.
Mr. E. E. Klein, M.D., F.R.S.	Chemist and Bacteriologist.
Mr. W. Williams, M.A., M.D., D.Ph. (Oxon), M.R.C.S., F.C.S., etc.	Medical Officer of Health to the Glamorgan County Council.
Dr. P. F. Frankland, F.R.S.	Professor of Chemistry in the University of Birmingham.
Dr. J. A. Voelcker	Consulting Chemist to the Royal Agricultural Society.
Mr. A. F. Firth	Managing Director of Messrs. T. F. Firth and Sons.
Mr. H. Beaumont	Fulling Miller and Finisher.
Mr. J. Crowther	Chairman of the West Riding of Yorkshire Millowners' and Occupiers' Association.
Mr. G. C. Hirst	Woollen Manufacturer.
Mr. J. Bruce	Manager of Tanneries and Currying Works.
Mr. E. Butterworth	Flannel Manufacturer.
Mr. H. A. Foster	Managing Director of Alpaca and Mohair Spinning Works and Manufactories.
Mr. G. Sheard	Woollen Manufacturer.
Mr. W. E. Walker	Tanner.
Mr. Harvey	Tanner.
Mr. J. Stanning	Representing the Calico Printers' Association, Ltd., and Bleachers' Association, Ltd.
Mr. Ross Gemmell	
Mr. A. J. King	
Mr. J. H. Mills	Clerk and Surveyor to the Crompton Urban District Council.
Mr. Alderman J. T. Simpson	Chairman of the Halifax Sewage Committee.
Mr. J. Lord	Engineer to the Halifax Sewage Committee.
Mr. Keighley Walton	Town Clerk of Halifax.
Mr. J. Jones	Borough Surveyor of Pudsey.
Mr. W. Hopkinson	Borough Surveyor of Keighley.
Mr. J. E. Sharpe	Engineer and Surveyor of Otley.
Mr. B. Powell	Engineer and Surveyor of Handsworth.
Mr. A. E. Fletcher, F.I.C.	Inspector under the Alkali Acts.
Mr. T. Carter Beeley, J.P.	Mayor of Hyde.
Mr. S. S. Platt, M.Inst.C.E.	Borough Engineer of Rochdale.
Mr. T. Stenhouse, F.I.C., F.C.S.	Public Analyst of Rochdale.
Mr. E. Ll. Morgan, A.M.Inst.C.E.	Borough Engineer of Bolton.
Mr. J. Ashton, F.C.S., F.I.S.E.	Chemist and Manager of the Bolton Sewage Works.

Name.	Qualification.
Mr. R. Johnson	Chairman of the Sewage Committee of Bradford.
Mr. E. A. Brotherton, M.P.	Manager Director of Manufacturing Works.
Mr. D. Howard, F.I.C., F.C.S.	Chemical Manufacturer.
Mr. C. A. Davis	Owner of Dyeworks.
Mr. W. F. Reid, C.E., F.C.S., F.I.C.	Vice-President of the Society of Chemical Industry.
Mr. H. Marshall	Representing the Halifax Traders' Committee.
Mr. C. W. Crossley	
Mr. P. G. Baldwin	
Mr. J. Smith	
Sir Charles A. Cameron, M.D.	Public Officer of Health in the City of Dublin.
Mr. S. Harty, C.E.	Engineer to the Dublin Corporation.
Mr. M. F. Purcell, M.Inst.C.E.	Civil Engineer.
Mr. Forbes Watson	Chemist to Messrs. Guinness, brewers.
Mr. J. C. Bretland, M.Inst.C.E.	City Surveyor of Belfast.
Dr. Lorrain Smith	Professor of Pathology at Queen's College, Belfast.
Mr. George Giles, M.Inst.C.E.	Chief Engineer to Belfast Harbour Commissioners.
Dr. W. S. Squire	Representing the Society of Chemical Industry.
Mr. Alderman Ellis	Tanner.
Mr. Thorp Whitaker	Representing the Bradford Dyers' Association.
Alderman Sir Bosdin T. Leech	Chairman of the Manchester Rivers Committee.
Councillor C. Dreyfus	Deputy Chairman of the Manchester Rivers Committee.
Mr. J. D. Watson, M.Inst. C.E.	Engineer and General Manager to the Birmingham, Tame, and Rea District Drainage Board.
Mr. C. F. Wike, M.Inst.C.E.	City Surveyor and Engineer of the Sheffield Sewage Works.
Mr. J. Haworth, F.C.S.	Chemist of the Sheffield Sewage Works.
Mr. T. Hewson, M.Inst.C.E.	City Engineer of Leeds.
Mr. J. Garfield, A.M.Inst.C.E.	Engineer of the Bradford Sewage Works.
Mr. G. H. Pickles, A.M.Inst.C.E.	Borough Surveyor, Burnley.
Mr. Raymond Ross, F.I.C., F.C.S.	Borough Analyst, Burnley.
Mr. J. Corbett	Engineer of the Salford Sewage Works.
Mr. J. Carter Bell, F.C.S.	Public Analyst.
Mr. J. Arnold	Manager of the Salford Sewage Works.
Mr. James B. Wilkinson, M.D. (Edin.), D.P.H., F.C.S.	Medical Officer of Health, Oldham.
Mr. A. H. Valentine, M.Sc.	Analytical Chemist, Oldham.
Mr. H. T. Bulstrode, M.A., M.D.	Medical Inspector of the Local Government Board
Mr. Phillips	Master of the Brewers' Company.
Mr. H. H. Waller	Vice-President of the West Riding Urban and Rural District Councils' Association.
Mr. R. B. Emsley	Solicitor to the West Riding Urban and Rural District Councils' Association.
Mr. W. B. Pindar	Secretary to the West Riding Urban and Rural District Councils' Association.
Mr. J. S. Martin	H.M. Inspector of Mines.
Captain Anderson	Chairman of the Whitstable Oyster Fishery Company.
Mr. Charles Petrie	Alderman of the City of Liverpool.
Mr. J. Wrench Towse	Clerk of the Fishmongers' Company.
Mr. R. A. Dawson	Representing the Lancashire and Western Sea Fisheries Committee.
Mr. H. Donnison	Representing the Eastern Sea Fisheries Committee.
Mr. H. W. Gibson	Representing the Kent and Essex Sea Fisheries Committee.
Mr. J. Cole	Oyster Merchant, Poole.
Mr. A. L. Scott	Oyster Merchant, Poole.
Mr. A. Brazier	Oyster Merchant, Southwick.
Mr. J. Kennett	Oyster Merchant, Emsworth.
Sir William Pink	Representing the Southern Sea Fisheries Committee.
Mr. St. Barbe	
Mr. G. H. Baxter	Representing the Chamber of Fisheries.
Mr. J. T. C. Nash, M.D. (Edin.), D.P.H.	Medical Officer of Health, Southend-on-Sea.

Name.	Qualification.
Mr. W. J. Bean	Oyster Merchant, West Mersea.
Mr. James Blamey, M.R.C.S.	Medical Officer of Health, Penryn.
Mr. Arthur Newsholme M.D., F.R.C.P. (Lond.)	Medical Officer of Health, Brighton.
Mr. James Niven, M.B.	Medical Officer of Health, Manchester.
Mr. J. H. Barber	Secretary of the Chamber of Fisheries and the London Fish Trade Association.
Mr. William G. Savage, M.D., B.Sc., D.P.H.	Medical Officer of Health, Colchester.
Mr. M. Fitzmaurice, C.M.G.	Chief Engineer of the London County Council.
Prof. Frank Clowes, D.Sc., F.I.C.	Chemist of the London County Council.
Mr. H. Williams, M.D.	Medical Officer of Health, Port of London.
Sir Shirley Forster Murphy, M.R.C.S.	Medical Officer of Health, London County Council.
Mr. C. C. Hutchinson	Counsel to the Lee Conservancy.
Mr. Geo. Corble	Clerk to the Lee Conservancy.
Messrs. Clapham and Fitch	Solicitors to the Lee Conservancy.
Mr. C. N. Tween	Engineer to the Lee Conservancy.
Mr. W. C. Young	Chemist to the Lee Conservancy.
Mr. R. B. Croft	Chairman of the Lee Conservancy.
Mr. E. B. Barnard	Member of the Lee Conservancy.
Mr. H. Nield	Member of the Lee Conservancy.
Mr. R. Phillipson	Secretary to the Thames Conservancy.
Mr. F. A. W. Drummond	Chief Inspector to the Thames Conservancy.
Mr. C. E. Groves	Analytical Chemist to the Thames Conservancy.
Dr. T. J. Browne	Medical Inspector, Local Government Board, Ireland.
Prof. E. J. McWeeney, M.A., M.D., D.Ph.	Bacteriologist to the Local Government Board for Ireland.
Mr. E. W. L. Holt	Scientific Adviser to Department of Agriculture, Ireland.
Dr. Cowie Mr. Allan Mr. Thorne Mr. Hopkins Mr. J. Robertson Mr. Doig Mr. Grant Glen Grant Mr. Fergusson Mr. Brown Mr. Mustard	Representing the South, East, West, and North of Scotland Malt Distillers' Association.
The Duke of Richmond and Gordon Mr. J. R. Findlay Mr. W. S. Menzies Mr. J. H. W. Grant	Representing Riparian Owners in Scotland.
Mr. Herbert Hughes, C.M.G.	Clerk of the Millowners' Association.
Mr. J. Selwyn Rawson	Millowner.
Mr. A. F. Somerville	Chairman of the Sanitary Committee of the Somerset County Council.
Mr. E. Halliwell	Chief Inspector of the Ribble Joint Committee.
Mr. George Reid, M.D., D.P.H.	Medical Officer of Health of the Staffordshire County Council.
Mr. J. Bolton	Manager of the Heywood Borough Sewage Purification Works.
Mr. J. H. Kershaw, F.C.S.	Chemist and Manager of the Corporation Sewage Works, Rotherham.
Mr. K. F. Campbell, M.Inst.C.E.	Borough Engineer of Huddersfield.
Mr. O. J. Kirby	Borough Engineer of Batley.
Mr. J. P. Wilkinson, M.Inst.C.E.	Engineer of the Manchester Sewage Works.
Mr. F. R. O'Shaughnessy, A.R.C.Sc., F.I.C.	Chemist to the Birmingham, Tame, and Rea District Drainage Board.
Mr. Geo. Watson, M.Inst.M.E., A. M.Inst.C.E.	Managing Director of the Horsfall Destructor Co.
Mr. W. F. Goodrich, A.M.Inst.M.E.	London Manager, Messrs. Meldrum Bros., Ltd.
Mr. J. E. Willcox, M.Inst.C.E.	Civil Engineer.

Name.	Qualification.
Mr. H. P. Raikes, A.M.Inst.C.E.	Civil Engineer.
Mr. J. Hunter, F.I.C., F.C.S.	Consulting Chemist.
Mr. J. B. Readman, D.Sc., F.R.S. (Edin.)	Consulting Chemist.
Mr. R. R. Tatlock, F.R.S. (Edin.), F.I.C., F.C.S.	Consulting Chemist.
Mr. J. H. Fullarton, M.A., D.Sc.	Formerly Scientific Adviser to the Fishery Board for Scotland.
Mr. Jas. Hendrick, B.Sc., F.I.C.	Public Analyst for the Counties of Aberdeen, Banff and Nairn.
Mr. Stevenson Macadam, F.I.C., F.C.S.	Analytical and Consulting Chemist.

(II) We have, by means of circular letters, obtained a large amount of assistance from many scientific men who have had special experience in regard to the subject of sewage disposal.

(III) A number of local authorities have carried out experimental investigations in association with the Commission, and have been good enough to furnish us with monthly records of the results of their experiments. These towns are as follows:—

Birmingham.	Leeds.	Rotherham.
Burnley.	Manchester.	Salford.
Heywood.	Oldham.	Sheffield.
Huddersfield.		

The reports furnished by these authorities are printed with the evidence. In each case the officers responsible for the local investigations were called before us to give evidence.

(IV) We have put under the systematic observation of our own officers a number of sewage farms and sewage works of different types.

The officers' reports on their observations of artificial processes are issued with this report as Appendix III. Their reports on the sewage farms were issued as an Appendix to our Fourth Report.

(V) We have carried out the following special investigations:—

Place at which the experiment was carried out.	Object of experiment.
Accrington	(a) For the purpose of ascertaining the relative difficulty of treating the same tank liquor, diluted and undiluted, on contact beds and on percolating filters. (b) To compare the purification effected in each instance by these two types of filter, under similar conditions in the one and in the other case.
Dorking	(a) For the purpose mainly of comparing septic tank liquor, precipitation liquor, and settled sewage derived from the same sewage, as to their amenability to subsequent oxidation by filtration. (b) To compare the reduction of suspended matter in the same sewage effected by the different processes of tank treatment, and to ascertain the quantities of sludge produced in each case. (c) Removal of suspended matter from percolating filter effluents. (d) Reduction in number of intestinal organisms in filtrates by means of sterilising agents, and comparison of the results obtained by this method with the effect of filtration through sand. (e) Comparative values of deep and shallow filters. [*See also* Ilford.]
Exeter (Belle Isle)	Digestion of sludge in septic tank. [*See also* Ilford.]
Guildford	For the purpose of ascertaining whether, by the addition of "oxychloride" solution to septic tank liquors, the unpleasant smell actually developed by such liquor may be destroyed without impairing the ability of the filter, subsequently dealing with the liquor so treated, to effect the requisite purification.
Hendon	Sterilisation of effluents.
Ilford	(a) Digestion of sludge in septic tank. (b) Comparative values of deep and shallow filters.

At some of these places channels have been provided along which the effluent has been allowed to flow, the main object being to ascertain whether effluents liable to bring about undesirable changes in the condition of a stream into which they are discharged can be clearly distinguished by chemical test from those which do not.

(VI) We have personally visited a large number of sewage works.

8. We wish to express our great indebtedness to the several local authorities, and to the many gentlemen from whom we have received assistance. Their names are far too numerous to mention.

Appendices to Report.

9. The following volumes are presented as appendices to this report :—

(I) The Evidence of Witnesses.

(II) A Summary of the Evidence.

In preparing this report we found it necessary to make a summary of the evidence.

The plan which was followed was to divide the subject up into chapters such as sewage, storm-waters, sedimentation tanks, septic tanks, standards, and so on, and then to sub-divide each chapter.

The evidence given on questions of primary importance was thus very briefly summarised and brought together.

We think that this summary may possibly be of general utility and we have therefore decided to publish it, but of course the evidence itself should be consulted by anyone wishing to make a complete study of the subject.

(III) Reports on the observations of artificial processes at the following places :—

Accrington.	Halton.	Maidstone.
Andover.	Hampton.	Newton le Willows.
Calverley.	Hartley Wintney.	Normanton.
Caterham.	Hendon.	Oswestry.
Chorley.	Hendon (Ducat filter).	Prestolee.
Clifton.	Horfield.	Rochdale.
Exeter (Main Works).	Kingston-upon-Thames.	Slaithwaite.
Exeter (St. Leonard's).	Knowle.	Withnell.
Guildford.	Little Drayton.	York.

(IV) Reports on the special investigations, mentioned on page 7, at Accrington, Dorking, Exeter, Guildford, Hendon, and Ilford.

Memorandum by Mr. Frye upon experiments carried out at Oldbury on the treatment of the sewage of that town.

Memorandum by Dr. McGowan as to measuring strength of sewage.

Report by Dr. McGowan and Mr. Frye on the estimation of the work done by filters which have been under the observation of the Commission.

Report by Dr. Houston on laboratory experiments on the biological purification of sewage.

Report by Dr. Houston on the biological character of B. coli in sewage and sewage effluents.

Reports by Dr. Houston on the results of the bacteriological examination of sewage and effluents from the sewage works at Bradford, Leeds, Manchester, and Ilford.

Report by Dr. Houston and Dr. McGowan on the sterilisation of the Lincoln water.

(V) Reports by Mr. Baldwin Latham, M.Inst.C.E., and Mr. R. A. Tatton, M.Inst.C.E., upon the effect of rainfall on the flow of sewage.

(VI) A report by Professor Letts and Dr. Adeney on the pollution of estuaries and tidal waters. In regard to this we may refer to paragraph 116 of our fourth Report, which was as follows :—

> "In connection with the question of standards as regards offensive putrefaction and injury to fish, we may state that much work has already been done, both in this country and abroad. We have therefore thought it desirable that the results of this work should be collected and collated. Mr. E. A. Letts, D.Sc., F.I.C., Ph.D., Professor of Chemistry at Queen's College, Belfast, and Mr. W. E. Adeney, D.Sc., Vice-President of the Institute of Chemistry, Curator and Examiner in Chemistry in the Royal University, Dublin, have kindly arranged to do this and to report to us on the question how far these results may suffice to show the conditions under which tidal rivers would become, (*a*) a nuisance in consequence of offensive putrefaction or (*b*) injurious to fish, either in consequence of the diminution of oxygen or the presence of poisons. The results so collected will, we hope, be of considerable use in enabling each Rivers Board to deal with waters under its jurisdiction."

To this report is appended a Paper by Mr. Gilbert J. Fowler, D.Sc., F.I.C., on the effects of discharge of septic tank sludge into a tidal estuary.

(VII) A copy of a circular letter on the question of standards for sewage effluents, and of the replies which were sent to us by chemists and others.

(VIII) Reports by Mr. W. Somerville, D.Sc., Mr. T. H. Middleton, M.A., M.Sc., and Dr. J. A. Voelcker upon experiments on the manurial value of sewage sludge.

Terms of Reference.

10. The first paragraph of the Terms of Reference requires us to state how (*a*) sewage, (*b*) sewage and trade effluents, and (*c*) trade effluents alone, may be properly treated or disposed of having regard to the requirements of

I.—The existing law.
II.—Public health.
III.—Economy and efficiency.

The second paragraph requires us to report by what rules, in relation to varying circumstances or requirements, should the particular method to be adopted be determined.

These terms open up a wide field of inquiry, and the second paragraph involves intimate study of various methods of treatment, many of which are new, under a very large number of different conditions.

GENERAL CONCLUSION.

11. Before dealing in detail with the numerous questions involved in our inquiry, we think it will be convenient that we should at once state our general conclusion on the question contained in the first paragraph of our Terms of Reference.

We are satisfied that it is practicable to purify the sewage of towns to any degree required, either by land treatment or by artificial filters, and that there is no essential difference between the two processes, for in each case the purification, so far as it is not mechanical, is chiefly effected by means of micro-organisms. The two main questions, therefore, to be considered in the case of a town proposing to adopt a system of sewage purification are, first, what degree of purification is required in the circumstances of that town and of the river or stream into which its liquid refuse is to be discharged; and, second, how the degree of purification required can, in the particular case, be most economically obtained.

The choice of a scheme must depend on a number of considerations which will be discussed later, but we may here state that we know of no case where the admixture of trade refuse with the sewage makes it impracticable to purify the sewage either upon land or by means of artificial processes, although in certain extreme cases special processes of preliminary treatment may be necessary.

PLAN OF REPORT

12. We propose to divide this Report into the following parts :—

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PART I. PRELIMINARY TREATMENT OF SEWAGE.

INTRODUCTORY REMARKS.

13. Sewage generally may be said to consist of a mixture of saline matter in solution and nitrogenous and carbonaceous organic matter in solution and suspension together with a certain amount of grit and mineral matter. The objects to be aimed at in its purification are the removal of the suspended matters and the oxidation of the remaining organic matter and ammonia.

There is a considerable amount of evidence to show that the oxidation of the organic matter during its passage through filters or land is chiefly a biological process, but as to the exact nature of the action which takes place very little is known.

One of our chemists, Mr. Colin Frye, carried out a * series of experiments at Leeds, in which he showed that, although a mature filter could not appreciably oxidise sewage sterilised with corrosive sublimate, it could oxidise sewage which had been sterilised with steam. Further, that a sterile filter could not appreciably oxidise sterile sewage.

We may also refer to some experiments which Dr. Houston, our bacteriologist, made during the year 1903. (Report by Dr. Houston on laboratory experiments on the biological purification of sewage: contained in Appendix IV.)

These experiments seem to suggest that the presence of such non-sporing bacteria as B. coli, B. proteus, etc., are not *essential* to purification, and that the work may be performed by other micro-organisms.

They also show that, although a filter may contain initially an enormous number of B. coli, if the liquid passing on to the filter contains none of these micro-organisms, this microbe rapidly disappears from the effluent, although the filter may still be able to support the life of many other bacteria. It is therefore to be inferred that sewage filters, when working properly, are not likely to provide suitable breeding grounds for pathogenic bacteria, although they allow a certain number of such bacteria to pass through them.

14. As regards the fermentative changes which occur in the purification of sewage, Dr. Adeney has made a large number of valuable experiments. His results have been published from time to time in the Transactions of the Royal Dublin Society, and in the proceedings of the Royal Irish Academy, and a connected account of the work is included in the † Report, which he and Dr. Letts have presented to the Commission on the Pollution of Estuaries and Tidal waters.

Dr. Adeney founds the following general conclusions on his work :—

General Summary.

"In the foregoing pages the chemical changes, which occur in a polluted water during so-called self-purification under aerobic conditions, and the laws underlying them, have been traced and established; and this has necessitated the discussion in minute detail of a large amount of experimental evidence of a varied character. A brief summary of the results arrived at, apart from experimental details, may therefore prove of some convenience to those interested in the subject.

"The most important change which occurs in an unpolluted water, when it is mixed with sewage or other water-borne refuse matters, is the more or less rapid absorption of its dissolved oxygen.

"The absorption may be effected in three different ways :—(1) The polluted water, from its own state of total or comparative de-aeration, reduces the aeration of the unpolluted water by simple dilution; (2) the polluted water may contain directly and easily oxidisable substances, which on becoming mixed with the unpolluted water will cause a more or less rapid loss of its dissolved oxygen; (3) the organic constituents of the sewage, which are not directly oxidisable (and they usually form the greater portion of the organic substances in it), and the ammonium compounds, are oxidised through the agency of water bacteria, and thus indirectly cause a loss of dissolved oxygen.

"These possible causes of de-aeration are enumerated in the order in which they would in all probability take effect under natural conditions. The first is obvious, although its importance has not been sufficiently recognised. Its effect can easily be differentiated from the other two, if the amount of dissolved oxygen, or as it is generally termed, the degree of aeration of the polluted water, be first determined, and this can be done without difficulty either by a gasometric or volumetric method.

* For a description of these experiments *see* our Second Report, Cd. 1178 (1902).
† *See* Appendix VI.

"The second cause of de-aeration is equally obvious, although its importance has also not been sufficiently realized. Such experiments as those recorded in Tables 34, 35, 35A, 36, and 37 prove that directly oxidisable bodies, from the rapidity with which they absorb oxygen, constitute a greater danger to the aeration of the water with which they become mixed than do indirectly oxidisable substances. Hence it is necessary to know the rate of absorption of oxygen caused by them as well as by indirectly oxidisable substances.

"It is impossible to foretell the influence of these two causes of de-aeration from any information derivable from the ordinary methods of chemical analysis. It is, however, possible to do so by means of the aeration method, and the foregoing pages have been largely devoted to a description of that method, and of the experimental investigation upon which it is based.

"A study of indirect oxidation by this method has shown that it is a physiological process analogous to the respiratory process of higher vegetable systems; but that it is only one, although the principal one, of a number of physiological processes concerned in the self-purification of a polluted water under aerobic conditions.

"It is unnecessary to discuss these in detail. It is sufficient for the study of polluted waters to recognise the possibility of processes of digestion (by enzymes), and to regard the remainder as together exercising one function, viz., the synthesis of the constructive materials required for the growth and multiplication of the bacteria, and at the same time to remember that there must result from these synthetical processes waste or by-products, which may be regarded as excretory substances.

"The chemical changes which are produced by the above processes may collectively be termed fermentative changes for convenience of reference.

"Experiments with samples of sewage and of polluted waters, of various descriptions, have been made, and it has been found that when they were severally mixed with unpolluted water in small proportions, within the limits of fouling, the fermentative changes which follow exhibit a definite and regular sequence. The organic matters first suffer complete fermentation, the products of change being carbonic acid, water, ammonia, and organic substances possessing the chemical and physical properties of the humus of cultivated soils, and of the organic substances to be found in all unpolluted natural waters, especially in those from upland surfaces.

"A second stage of change subsequently ensues, in which these humus matters and the ammonium compounds are further fermented, the resulting products being carbonic acid, nitric acid and water.

"The inorganic products of the first stage of fermentation result from the action of the respiratory process, and possibly also of enzymes; and the humus-like substances are waste products from the synthetical processes.

"It is a point of interest to note that free nitrogen has not been observed amongst the products of the fermentation of organic substances in water under aerobic conditions, although it does undoubtedly occur amongst the products of fermentation in percolating filters even when the conditions therein are wholly aerobic. It is a question, no doubt, of intensity of oxidation. The filter presents conditions for an extremely rapid and intense oxidation; while water in large bulk, owing to the sparing solubility of oxygen in it, can only allow a sluggish oxidation to proceed in it.

"Experiments with distilled water solutions of simple organic substances of known composition have shown that the respiratory process is one of simple oxidation, and that the organic matters affected by it are completely oxidised to the inorganic products, carbonic acid, ammonia and water. The oxidation may either be complete step by step as the fermentation proceeds, or only partial at first but finally complete, according to the chemical properties of the substances undergoing fermentation.

"In the simple solutions employed in these experiments, it was evident from the composition of the organic substance dissolved in each and from the ratio of the carbon dioxide formed to oxygen absorbed, on its complete fermentation, that the oxygen was almost, if not entirely, taken up by the respiratory process. Other experiments, however, have shown that it is quite possible under certain exceptional conditions as to the composition of the fermenting substances, for the synthetic processes to take up relatively considerable quantities of oxygen. Whether oxygen is or is not taken up by these processes appears to be a question of composition of the fermenting substance, as might be expected. In ordinary cases, however, of polluted waters, the composition of the polluting substances generally appears to be such that during their fermentation the absorption of oxygen is practically confined to the respiratory process.

"Enzymic action is intimately associated with the respiratory process in the fermentation of many organic substances. The chemical changes induced by them are principally hydrolytic, and the products are generally simplifications of the original body; and these undergo further fermentative change. Only in the case of urea do they bring about a complete change to the ultimate products, carbon dioxide and ammonia.

"Sometimes enzymic changes occur with almost explosive velocity; *e.g.*, asparagin, when present in the fermenting water, is hydrolysed with extreme rapidity, the whole of it being converted into aspartic acid and ammonia at the very commencement of the fermentation, the hydrolysed product, aspartic acid, then undergoing complete fermentation.

"In other cases, enzymic change may proceed extremely slowly, very much more so than the other fermentative changes which may be going on in the same water. Urea when present in some polluted waters is an example of this.

"There are some other substances which may occur in polluted waters, *e.g.*, native albumins and fats, which require to undergo enzymic change before they can be readily fermented by water bacteria.

"The chemical changes which are brought about by the respiratory process and by enzymes may be regarded as yielding a continual supply of energy to the bacteria. They effect the complete oxidation of 70 to 80 per cent. of the organic substances originally present in the polluted water.

"The new material resulting from the synthetical process accounts probably for about 5 per cent., or even less, and the waste products for the remaining 15 to 25 per cent.

"As regards possible relationships between the volume of carbon dioxide formed to oxygen absorbed in a polluted water, it is obvious there can be no very definite one, especially when the water contains directly and easily oxidisable substances, *e.g.*, sulphides, etc., in addition to indirectly oxidisable ones. As a matter of fact, however, in the case of most waters polluted by fresh sewage, a fairly constant relationship has been observed, the ratio of carbon dioxide to oxygen being approximately as 1 : 1. If the sewage be putrefactive and contain sulphides, the ratio may be much less, *e.g.*, the ratio for the septic tank liquor employed for the experiments recorded in Table 39 is as 1 : 1·3.

"After the completion of the fermentation of the organic matters, a second stage of change, as already noted, sets in, and during it the products of the first stage, that is, the ammonium compounds and the humus matters, undergo further fermentation. As a result the former are completely oxidised to nitric acid and the latter more or less completely to carbon dioxide and nitric acid. The point of interest and importance in this stage of fermentative changes is the influence of the humus matters on the oxidation of the ammonium compounds.

"Laboratory experiments have shown that they not only accelerate the fermentative changes, but that their presence is necessary for the oxidation of the ammonium compounds to nitric acid. When they are entirely absent, the oxidation is not carried under ordinary conditions beyond nitrous acid.

"When the ammonium compounds are present in slight excess of the humus matters, both may be completely fermented, the inorganic products being carbon dioxide, water and nitric acid.

"The changes which humus matters may undergo when in excess of the ammonium compound appears to be very variable. For example, when fresh, a portion of their carbon is readily oxidised to carbon dioxide, and then, if unassociated with compounds of ammonia, they cease to undergo much further change.

"The volume of oxygen actually absorbed in the second stage of fermentation does not bear a constant ratio to the oxygen theoretically equivalent to the nitrous and nitric oxides formed. The volume may be greater than the theoretical, in the proportion of 10 : 8·14 (Table 19, Experiment 1 and 1*a*), if humus matters are wholly absent; or less, *e.g.*, 10 : 13·5 (Table 19, Experiment 2), if these are present in large quantities and are freshly formed.

"Where, as in ordinary cases of polluted tidal waters, humus matters are unlikely to be present in any but small proportions, the volume of oxygen required for the oxidation of the ammonia to nitric acid can be calculated with sufficient accuracy from the equation :—

$$2\ NH_3 + 4\ O_2 = N_2O_5 + 3\ H_2O.$$

"On comparing together the changes which progressively occur in the two stages of fermentation which have been described, it becomes evident that the oxidation of ammoniacal nitrogen to nitrous and nitric acids constitutes the central feature of the second stage, just as the oxidation of organic carbon to carbon dioxide constitutes the central feature of the first stage. It may be concluded, therefore, that the products nitrous and nitric acids of the one stage are the analogues of the product carbon dioxide of the other stage. The first stage of fermentation may consequently be termed the carbon-oxidation stage, and the second the nitrogen-oxidation stage. These terms have the advantage of emphasising a fact which it is necessary to keep in mind in dealing with the subject of water pollution; it is that the sequence of the chemical changes, which occur during self-purification under aerobic conditions, takes place in accordance with thermo-chemical principles.

"A classification of the substances which may occur in polluted waters may be made, based on their behaviour towards the dissolved oxygen of the water, as follows :—

(1) Directly oxidisable substances.
(2) Indirectly oxidisable substances.

"These latter may be further sub-divided, according to their fermentative properties into—

(*a*) Carbon oxidisable substances, that is, most known organic substances except antiseptics.
(*b*) Nitrogen fermentable substances, that is, the waste products from a first stage fermentation, and ammonium compounds.

"Not only do the fermentative changes in a polluted water follow a definite and regular sequence, but the relationship between the oxygen absorbed and the products formed, and between both of these and the quantities of polluting matters originally present, are quantitative according to the following law :—The quantities of oxygen absorbed, and of products formed, on the completion of each stage of aerobic fermentation, is constant for similar volumes of the same polluted water, provided that the dissolved oxygen is in excess of the fermenting matters.

"It must be granted from the above brief description of the fermentative changes which occur in a water during self-purification under aerobic conditions, that the significance of the presence of indirectly oxidisable substances in water depends not upon their exact quantity and chemical composition, but upon their fermentative properties and on the rate at which they will absorb oxygen from the waters with which they are mixed The same remark applies with equal force to directly oxidisable substances."

"It must also be granted that the methods which are at present employed for the analysis of sewage and of sewage effluents, which were originally worked out for the analysis of potable waters, do not afford information of this kind. The aeration method has consequently been proposed for the purpose. As may be gathered from the perusal of pp. 67–91 it is possible to determine by its means the rate of absorption as well as the total absorption, of oxygen which a sewage or sewage effluent is capable of setting up when mixed

in small proportions with unpolluted river or tidal water, during direct oxidation as well as during both stages of indirect oxidation. From the description of the method given on p. 96, it will be seen that several modifications in working can be adopted according to the object in view, that is to say, whether it be desired to study the fermentative changes step by step in their entirety, or simply to determine the rate of, or total, absorption of oxygen during them. The modifications required for the latter purpose can be so simply operated that untrained persons can be taught to carry them out without difficulty.

"Another phase of the subject of the self-purification of slightly polluted waters, and a scarcely less important one, is the rate at which the dissolved oxygen in such is replenished from the atmosphere under natural conditions, when it is being absorbed by polluting matters. It is obvious that definite information is required on this question before it will be possible to formulate standards of impurity for the protection of river and tidal waters from over-pollution.

"Experiments have been described which afford some fairly trustworthy information on this subject. The results of these experiments were quite unexpected, since they show that the slow rate of re-aeration of large volumes of de-aerated tidal water under calm weather conditions is not due to the slow process of mixing by thermal current or of diffusion of the dissolved gas after it has been taken up in solution by the surface layers of the waters exposed to the air. On the contrary, it has been shown that the slowness of re-aeration is due to retardation of the process of solution at the water's surface, and that when oxygen has become dissolved at the surface from the atmosphere, it is drawn with comparative speed through the water, apparently by some unexplained process of gravitational streaming. It has also been shown that long columns (6 feet) of de-aerated fresh or sea water enclosed in narrow glass tubes of small bore are comparatively quickly re-aerated when the surfaces of the columns were kept continuously broken, either by a mechanical stirrer or by a slow current of air delivered by an inlet tube dipping a little below the surface.

"It has, furthermore, been found from these experiments that the aeration of the sea water columns was effected much more rapidly than that of the fresh water columns, and that the dissolved gases showed practically no tendency to accumulate in the surface layers of the sea water columns, but passed almost as quickly through them as they were dissolved, with the result that the degree of aeration of the water is found to be nearly uniform throughout the length of the column, if it be tested at different depths at any time during the process of aeration; while in the case of the fresh water columns the dissolved gases did show a tendency to accumulate in the upper layers, and did not pass so rapidly to the lower layers."

15. Dr. Fowler, Professor Frankland, Mr. Harrison, Dr. Letts, Dr. Reid, Mr. Stoddart, Dr. W. Owen Travis and many others have also carried out numerous experiments with a view of elucidating some of the scientific questions involved in the purification of sewage, but notwithstanding the fact that a considerable amount of exact knowledge has been gained as the result of the experimental investigations which have been already made, there are many questions in regard to which our knowledge is exceedingly limited.

As regards the actual disposal of sewage on a practical scale, Colonel Harding and Mr. W. H. Harrison, at Leeds; Dr. Fowler, at Manchester; Mr. J. D. Watson and Mr. F. R. O'Shaughnessy, at Birmingham; Messrs. Willcox and Raikes, and Dr. George Reid at Hanley, Newcastle-under-Lyme, and elsewhere; Mr. A. H. Valentine and Dr. J. B. Wilkinson, at Oldham; Messrs. Raymond Ross and G. H. Pickles, at Burnley; Mr. Joshua Bolton, at Heywood; Mr. J. H. Kershaw, at Rotherham; Mr. K. F. Campbell, at Huddersfield; Mr. J. Carter Bell, at Salford; Mr. C. F. Wike and Mr. J. Haworth, at Sheffield, and others have carried out many valuable experiments in regard to certain methods of purifying sewage. These gentlemen have placed before us all their results, and have been most liberal in assisting us in every possible way.

16. As regards our own work we have, in an earlier paragraph, explained the general scope of our investigations.

Throughout our inquiry we have endeavoured to gain such knowledge as would enable us to pass from the stage of broad qualitative observation to one of exact quantitative statement, but in regard to many matters this transition is not at present practicable, and, therefore, we can only comply in general terms with the terms of reference which directed us to state "by what rules, in relation to the nature or volume of sewage, or the population to be served, or other varying circumstances or requirements, should the particular method of treatment and disposal to be adopted be determined."

The circumstances of different places are of endless variety and there are many varieties of treatment, any one of which will be successful, if properly carried out. The main question to be determined in each case is which of these methods will be cheapest, having regard to the local circumstances.

We propose to discuss various methods of disposal in some detail, and then to indicate, in broad terms, the considerations which should be borne in mind in the selection of a method of treatment for any particular case.

STRENGTH OF SEWAGE AS AFFECTING PURIFICATION.

17. The composition of different sewages varies to a large extent, and it is important to consider how strength of sewage, as affecting purification, may be measured. The amount of filtration necessary to produce an effluent of any given standard of purity varies, to a wide extent, with different sewages.

The variations in strength of the sewage of different towns depend chiefly on the amount and nature of the water supply; the extent to which the houses are provided with water closets; whether a separate system of sewers is provided for storm waters; and what trade effluents (if any) are admitted into the sewers. Dr. Fowler has pointed out that a fairly accurate idea of the strength of sewage, as affecting purification, may be arrived at by measuring the number of gallons of sewage per head per day arriving at the outfall and making allowance for the other factors, while other witnesses have suggested that the usual tests, such as "oxygen absorbed", are sufficient. 22735.

18. Where, however, a more exact measure of strength is needed, we are inclined to think not only on theoretical grounds, but also as the result of experience, that this can at present best be obtained by ascertaining the amount of dissolved oxygen taken up during the complete, or practically complete, oxidation of the organic and ammoniacal matter in the sewage. 25578.

The purification of sewage is to a large extent a process of indirect oxidation through the agency of bacteria, and one of the chief things required to be known about any particular sewage is how much oxygen is required for its complete oxidation. The rate at which the sewage will take up oxygen is also a factor of importance, in that it furnishes information as to the character of the organic matters.

The dissolved oxygen test is a biological process, and it differs from the ordinary tests—such as oxygen absorbed from permanganate—in that it takes account of practically the whole of the organic matter, and not merely that of a particular kind.

The amount of oxygen which a sewage can take up is, however, only an approximate measure, for purposes of purification, of its strength, as some constituents of sewage are oxidized by filters or land more readily than others, and the proportion which they bear to the total organic matter varies largely in different cases.

19. To determine the amount of oxygen which a sewage requires for its oxidation, a definite quantity of the sewage is allowed to remain in contact with a known excess of oxygen until it is completely oxidised, and the oxygen remaining over is then measured. This can be done either:

(*a*) By diluting the sewage largely with good tap water, estimating the oxygen in solution in a portion of the mixture, and allowing the remaining portion to stand in a bottle which is filled completely and shut off from all access of air. At least two months must be allowed for this, after which the oxygen remaining in solution is determined. The difference represents the oxygen used up.

(*b*) By keeping the sewage, without diluting or diluting only very slightly, continuously aerated in a bottle containing a measured excess of air. Dr. Adeney, who has suggested this plan, has found it to be very much more rapid than the first.

20. A serious disadvantage in the use of the dissolved oxygen test as a measure of the strength of sewage is that it requires, even with the more rapid method suggested by Dr. Adeney, a comparatively long time to oxidize the organic matter completely by dissolved oxygen. From the results of a considerable number of laboratory experiments with method (*a*), we thought that a period of about two months might be generally taken as sufficing for the oxidation of nearly all the oxidisable matter, excluding to some extent,

at least) cellulose and fat. Later results, however, appear to show that this may be too short a time under ordinary conditions of experiment. Though we have not made enough observations on the point to speak definitely, we are satisfied that the oxidation of cellulose and fat in diluted sewage, under the aerobic conditions of our experiments and at ordinary temperature, is slow*. In practice, however, there are but few instances of the treatment of *crude* sewage on biological filters, and the amounts of cellulose and (probably) of fat which are present in the liquids usually treated (settled sewage, septic tank liquor, and precipitation liquor) are relatively small.

By method (*b*) and by making use of a mechanical shaker attached to a suitable gas apparatus, Dr. Adeney† succeeded in oxidizing strong septic tank liquor by means of atmospheric oxygen, without any dilution with water, while he followed the course of the reaction by determining at different intervals of time the quantity of oxygen required by known volumes of the liquor. In this way he reached the nitrification stage of the process in twelve days. The method is thus a great advance, as regards time required, upon the dilution method.

Recently Dr. Adeney has invented an ingenious apparatus for carrying out the dissolved oxygen absorption test, by which the rate of absorption of oxygen as well as the total amount of oxygen taken up can be readily measured. It is described on p. 438 of Appendix VI.

21. With a view to ascertaining whether the dissolved oxygen absorption test bears any more or less constant ratio to other and more rapid tests, Dr. McGowan, our chemist, has made a number of observations.

He gives figures to show that the amount of dissolved oxygen which a sewage would take up during oxidation can be arrived at, with a fair degree of accuracy, by a calculation based on the "oxygen absorbed" figure and the figures of analysis of the ammoniacal and organic nitrogen.

A copy of Dr. McGowan's Memorandum is printed in Appendix IV.: the following extract shows the formulæ which he suggests:—

"By applying the results given in Table A it would appear that the relative 'strength' of a sewage liquor can be arrived at rapidly, with a fair degree of accuracy, by estimating the ammoniacal and organic nitrogen and the 'oxygen absorbed" from strong acid permanganate *at once* and *in 4 hours* at 27°C. (80°F.), and afterwards making use of one of the following alternative formulæ:—

(1) Column 9.	For *Sewages.*	(Ammon. + Organic N.) × 4·5 + (Oxygen abs. in 4 hrs. × 6·5).
	For *Septic Tank Liquors.*	" " " + (" " × 6·5).
	For *Precipitation Liquors.*	" " " + (" " × 6·0).
(2) Column 10.	For *Sewages.*	(Ammon. + Organic N.) × 3·0 + (Oxygen absorbed in 4 hrs. × 8·0).
	For *Septic Tank Liquors.*	" " " + (" " " × 8·0).
	For *Precipitation Liquors.*	" " " + (" " " × 7·5).
(3) Column 8.	For *Sewages,*	(Ammon. N. + 4·5) + (Oxygen absorbed in 4 hrs. × 8·0).
	For *Septic Tank Liquors.*	" " + (" " " × 7·5).
	For *Precipitation Liquors.*	" " + (" " " × 7·5).

"The variations in the individual ratios given by the same kind of sewage liquor in Table A are too great to allow of this method of arriving at their 'strengths' being more than approximate. Probably the variations would have been less marked if all the long aerations had been carried out in mercury-jointed bottles, and if the small quantities of gases evolved had been allowed for. Further experiments will, however, settle the point."

* One part of cellulose, by weight, requires only 1·2 parts of oxygen for its complete oxidation; one part of fat requires nearly 6 parts of oxygen. Tri-palmitin $C_3H_5(OC_{16}H_{31}O)_3$ is taken here to represent fats generally.

† The Pollution of Estuaries and Tidal Waters. Report to the Royal Commission on Sewage Disposal, by Professor Letts and Dr. Adeney, p. 101 *et seq.* See Appendix VI.

As regards Dr. McGowan's suggestion, we consider that until the method of calculation which he proposes has been compared with the results of direct experiment on a larger number of *different* sewages, no statement can be made as to its precise accuracy. We have, however, found it convenient to use the method in the preparation of this Report in order to bring results at different places into line.

In later sections we shall frequently define the strength of a sewage or sewage liquor by a number. This number is intended to represent the number of parts, by weight, of dissolved oxygen which 100,000 parts of the liquid would take up during the oxidation of the oxidizable matter contained in such liquid. It will not, however, have been arrived at by direct experiment, but by a calculation, according to the first of the formulæ suggested by Dr. McGowan, and it must therefore only be regarded as approximately representing what it is intended to represent.

22. As bearing on the question of strength of sewage as affecting purification, we may refer to our experiments at Accrington.‡

A double contact bed plant filled with rather fine and graded material was provided in duplicate. On one set of contact beds, septic tank liquor was treated at the rate of 80 gallons per cube yard per day; on the other set, the same septic tank liquor diluted with an equal volume of tap water was treated at double the rate. The percentage purification was slightly greater in the case of the contact beds treating the weaker liquor.

Two exactly similar percolating filters, 9 feet deep, filled with coarse material, were also provided.

On one filter, septic tank liquor was treated at the rate of 100 gallons per cube yard per day; on the other filter, the same septic tank liquor diluted with an equal volume of tap water was treated at double the rate. In this case the percentage purification was slightly greater with the filter treating the stronger liquor.

The differences in the percentage purification were, however, in both plants so small that we think it may be taken broadly that, within ordinary limits of concentration and volumes treated, it is the amount and nature of the organic impurity present which mainly determine in practice the ease or difficulty of purification; in other words, that, within practical limits, mere dilution does not affect the size of the filtering plant which is necessary. Of course if the dilution is so great as to cause water-logging of the filters, their purifying power would be seriously diminished, and this statement would not hold good.

The Accrington experiments are dealt with more fully on pages 110 to 117 of this Report.

‡ *See* Appendix IV. for a full account of these experiments.

PRELIMINARY PROCESSES FOR THE REMOVAL OF SUSPENDED MATTERS.

General Observations.

23. The evidence which we have received and our own experience show that it is generally more economical to remove from the sewage, by a preliminary process, a considerable proportion of the grit and suspended matter, before attempting to oxidize the organic matters on land or in filters.

It is true that at Leeds, Sutton, Hampton, Hendon (the Ducat filter), Market Drayton (the Ducat filter), and elsewhere, crude sewage has been satisfactorily purified in filters with almost complete absence of nuisance, but at most of those places, this plan has been abandoned because of the rapid choking of the filters.

As regards the treatment of crude sewage on filters, we have ourselves made detailed observations at the following places :—

Hampton.	Maidstone.
Hendon.	Newton-le-Willows.
Little Drayton.	Withnell.

Reports on these observations are published in Appendix III.

There are also many cases in which crude sewage has been passed over land, but the evidence shows that land treatment of crude sewage is liable to give rise to nuisance by the accumulation of solids on the surface of the land. Moreover, in some cases these solids are apt to form an impervious layer which interferes with the aeration of the soil, and so impairs the efficiency of the treatment.

Screening.

24. On arriving at the works the sewage is usually passed through coarse screens for the purpose of removing the grosser suspended matters, such as sticks, cloths, paper, corks, etc.

The removal of such suspended matters is almost essential where the sewage has to be pumped, and in other cases it is usually considered an advantage.

Although the amount of suspended matter which is removed by coarse screens bears only a small proportion to the total suspended matter, the screenings have some manurial value, and there is usually no difficulty in getting farmers and others to take them away.

The screens in use are of various kinds, and some are provided with automatic apparatus for clearing them.

Experiments with fine screens were carried out at Leeds,* with a view to ascertaining whether it was practicable to remove a large proportion of the total suspended solids in this way.

With a screen of a mesh of 30 to the inch, however, rather less than 10 per cent. of the total of the suspended matters was removed.

The use of fine screens is always attended with difficulty as they choke readily, and the experience of Leeds seems to show that where tank treatment is provided as a preliminary process, the cost of fine screens would not be justified.

In the circumstances obtaining at Birmingham, Mr. Watson prefers not to screen the sewage, but to allow the whole of the suspended matter to flow, with the sewage, to the first sludge tanks. The sludge itself is screened, to remove the grosser solids, before it is disposed of on land.

* Report on experiments in Sewage Disposal, June, 1905, by Col. T. W. Harding and Mr. Harrison.

Grit or Detritus Tanks.

25. Most of the witnesses whom we have examined favour the removal of the heavy suspended matters, such as grit or road detritus, as a first operation, and our own observations have shown that in most circumstances it is desirable to provide tanks for this purpose.

These tanks are usually designed so that the speed of flow will allow the mineral matters to settle out of the sewage, while the bulk of the organic suspended matters are carried forward.

The extent to which the heavy matters need be settled out of the sewage as a first operation depends in some measure on the subsequent treatment which is to be adopted.

Where septic tanks are to be used which will only be cleaned out at long intervals of time, fairly thorough preliminary settlement of grit is generally desirable. The removal of the sludge which has accumulated over a long period in a septic tank is, as a rule, a matter of difficulty, as the sludge is often so thick that it cannot be pumped unless sewage or water is mixed with it. Much mineral detritus in the sludge increases this difficulty.

We also consider that in the case of septic tanks from which a portion of the sludge will be removed periodically, preliminary settlement of the mineral detritus is, as a rule, desirable. Tanks to be used in this way are generally provided with sludge channels formed in the concrete floor. If the sludge to be drawn off contains much mineral detritus, it will not flow to the channels but will remain in heaps at the side.

In the case of a very small works (flow of sewage up to, say, 10,000 to 15,000 gallons per 24 hours) where septic tanks are used for the preliminary process, the provision of grit or detritus tanks which require constant sludging may necessitate more labour than would otherwise be the case, and in such circumstances it may be more economical to allow everything to go forward into the septic tank. Although the presence of the mineral detritus in the general tank sludge would make the sludging of the tank a more difficult operation, the saving of labour between the intervals of sludging would probably more than balance the extra cost of removing the sludge.

Where precipitation or sedimentation tanks are to be used, and especially if the district is sewered on the combined system, it will, we think, generally be found better to settle out a considerable proportion of the mineral detritus before allowing the sewage to pass into the tanks. The necessity of giving thorough preliminary settlement of the grit is not, however, in these cases of so great importance, for the presence of grit in sludge renders the latter more amenable to pressing and drying.

Sedimentation Tanks.

26. All tanks are sedimentation tanks, but it is convenient to limit the expression to tanks in which the sewage is allowed to settle, without the aid of chemicals, and from which the sludge is frequently removed.

In some cases the tanks are allowed to stand full, and the supernatant liquid is drawn off by a floating arm. In other cases the sewage is allowed to flow through the tanks slowly, but continuously.

Quiescent Sedimentation.

27. Experiments which were carried out at Leeds and Sheffield showed that, with the sewages of those cities, quiescent settlement for two to three hours was sufficient to remove a large proportion of the suspended solids entering the tanks, and to produce a fairly good tank liquor.

No precise rule, however, can be laid down as to the period of quiescence which is required to effect a given reduction of the suspended solids.

Certain kinds of sewage contain more solids which settle very slowly, than other kinds.

For example, a large proportion of the solids in sewages which contain brewery or tannery waste, or wool scouring liquor, are difficult to settle.

To maintain this form of settlement in a highly efficient condition, the deposit in the tank must be removed after every first or second filling.

Continuous Flow Sedimentation.

28. We have had experience of this method of sedimentation at Clifton, Halton, Oswestry, and Dorking. The following table shows the settlement effected at these places:—

Place.	Shape of Tank.	Dimensions of Tank.	Time allowed for settlement.	Rate of flow per minute in inches.	Solids (in parts per 100,000) reduced from
Clifton - -	Rectangular	39′ × 5′ × 4′.	5·3 hours.	1· 7″	49 to 24.
Halton - -	"	25′ × 12′ × 6′.	15·5 "	0·66″	17·7 to 10·7
Oswestry - -	"	70′ × 15′ × 4′ 6″.	4·1 "	3·40″	32·0 to 15·8
Dorking - - -	"	18′ 6″ × 4′ 6″ × 4′ 9″.	11·9 "	0·31″	20·8 to 10·1

The amount of settlement does not depend alone on the period of flow, but also on various other factors, such as the shape of the tank, the nature of the suspended matter in the sewage, and the length of time during which the tank is used without being cleaned.

If the tank is not cleaned out frequently, the deposited sludge begins to ferment and the gas produced carries suspended matter with it, as it rises to the surface of the liquid.

As a general rule, if the filters to be used are constructed of fine material, on which it would be undesirable to put a large amount of suspended matter, we consider that the period of flow should be from 10 to 15 hours, and that the tanks should be cleaned out at least once a week.

Before either kind of sedimentation is adopted, the nature of the suspended matter in the sewage which is to be dealt with, and the rate at which it settles, should be considered.

Should Sedimentation Tanks be used in series or in parallel?

29. It would usually be more advantageous to use continuous flow sedimentation tanks in parallel than in series, for the following reasons:—

With tanks of ordinary dimensions, the minimum rate of flow is obtained where the tanks are used in parallel.

As a rule, after a certain percentage of the suspended solids has settled out of a sewage, little further advantage is gained by continuing the same tank treatment, the suspended solids remaining in the supernatant liquid being of low specific gravity, and depositing very slowly unless quiescent settlement is given. In practice, therefore, so soon as this maximum quantity of solids is settled out as a result of continuous flow settlement, little advantage is obtained by passing the liquid through another tank at a similar rate.

If sedimentation tanks are used in series, there is a natural tendency to allow the last tank in the series to run too long without being cleaned out. The result in such a case is that the sludge, lying at the bottom of this tank, even though small in amount, begins to ferment with the formation of gas bubbles, which carry suspended matter up into the liquid.

There is rather more difficulty in cleaning tanks which are used in series than those used in parallel, owing to the fact that the first tank in a series is usually found to contain very thick sludge, which may, in some cases, have to be mixed with sewage before it can be got to flow into the sludge main; while in the last tank the sludge is very thin and watery. At a large works, however, where there are special facilities for removing and dealing with dense sludge, such as would accumulate in the first tank, this difficulty would not be serious.

Our experience with continuous flow settlement tanks used in series has been obtained chiefly at Halton, and, with continuous flow settlement tanks used in parallel, at Oswestry and Shipley. As the same arguments apply to the settlement of precipitated sewage, however, we may also adduce the results of our observations at Kingston, Maidstone, and Hendon, for the use of tanks in series, and at Horfield, for the use of tanks in parallel.

It is desirable to use quiescent settlement tanks in parallel, in order that the period of actual quiescent settlement (*i.e.*, apart from filling or drawing off) should be as long as possible.

Nuisance.

30. Settlement of sewage by sedimentation does not give rise to serious smell during the time the tanks are actually at work. When the tanks are sludged, there is considerable smell, and since tanks used for quiescent settlement have to be sludged more often than those in which there is a continuous flow, there is more liability to recurring nuisance in the former case.

In the case of tanks used for settling domestic sewage, there is only slight local smell during the process of settlement. We have had practically no experience of the sedimentation of sewage containing brewery or tannery refuse in quantity, but in such cases the smell would, no doubt, be markedly increased.

Septic Tanks

31. The notion that the solid matter of sewage would be digested by passing the sewage through a sealed tank is by no means novel, but it does not appear to have had any extensive practical application until Mr. Cameron, who held the office of City Surveyor of Exeter, proposed the adoption of the "septic tank treatment" for that city.

At that time it was claimed that the septic tank possessed the following, among other, advantages:—

That it solved the sludge difficulty, inasmuch as practically all the organic solid matter was digested in the tank.

That it destroyed any pathogenic organisms which there might be in the sewage.

That sewage which had passed through a septic tank was more easily oxidized than sewage from which the solids had been allowed to settle, either with or without the aid of chemicals, in tanks which were frequently cleaned out.

32. As regards the first of these claims, it is now clearly established that, in practice, all the organic solids are not digested by septic tanks, and that the actual amount of digestion varies to some extent with the character of the sewage, the size of the tanks relative to the volume treated, and the frequency of cleansing.

At Huddersfield, Mr. Campbell estimated that about 38 per cent. of the solids 21,633
were converted into gas or digested; at Leeds, Mr. Harrison put the figure at about 21,994
30 per cent.; at Manchester, Dr. Fowler says that possibly, though not certainly, 22,923
about 25 per cent. of the total suspended matter is digested or converted into gas; at 23,611
Sheffield, Mr. Haworth puts the digestion at 32·9 per cent., while at Birmingham, 24,985
Messrs. Watson and O'Shaughnessy say that the figures available indicated a digestion of not more than 10 per cent. of the suspended matter entering the tanks.

From careful observations, extending over two years, which we made at Exeter and Ilford, we found that, without allowing a correction for colloidal matters, the digestion at Exeter was about 25 per cent., and at Ilford about 30 per cent.

The sewages of both places were domestic in character: the Ilford sewage was of average strength; and the Exeter sewage about two-thirds as strong. In each case the tank was sufficient to enable it to hold a day's (24 hours) flow, and no sludge was removed from either tank during the experiment. A detailed report of the experiment is contained in Appendix IV.

33. As regards the second claim, we find as a result of a very large number of observations that the sewage issuing from septic tanks is, bacteriologically, almost as impure as the sewage entering the tanks.

34. As regards the third claim, the evidence which we received was conflicting. Some witnesses stated that septic tank liquor was more easily treated than sewage from which the solids had been settled, either with or without the aid of a precipitant, while others expressed a contrary view.

The point is one of great importance in the purification of sewage, and we therefore thought it desirable to investigate it somewhat exactly.

After visiting several places, the Dorking sewage was selected as a suitable domestic sewage with which to experiment, and the Dorking Urban District Council were good enough to grant us the requisite facilities for making the experiment at their works.

For the purpose of the experiment, three identical percolating filters were constructed. One was fed with settled sewage, one with sewage which had been subjected to chemical precipitation, and one with septic tank liquor.

35. The experiment, which was under the supervision of our own resident chemist, Mr. Eric H. Richards, and was carried on for over a year, conclusively proved that in the case of an ordinary domestic sewage, such as that at Dorking, septic tank liquor is not more easily oxidized on its passage through filters than the other liquids.

The experiment is fully reported on by Mr. Richards in his Report, which is published in Appendix IV.

The results of careful experiments previously carried out at Rochdale by Mr. Platt, at Leeds by Mr. Harrison, at Huddersfield by Mr. Campbell, and at Sheffield by Messrs. Wike and Haworth, at all of which places the sewage contains trade effluents from manufacturing processes, agree with our Dorking results.

36. It must, therefore, be said that some of the more important claims which were originally advanced in favour of septic tank treatment have not stood the test of experience. At the same time, we think that in certain circumstances the adoption of this method of treatment, as a preliminary process, is efficient and economical.

Suspended Solids issuing from Septic Tanks.

37. The settlement of the suspended solids in septic tanks is not usually very thorough, and the evidence shows that at many places the liquor issuing from the tanks contains on the average from 15 to 20 parts of suspended solids per 100,000.

At the places which we have had under observation the average figures were as follows:—

SEPTIC TANKS.

Name of place.	Character of sewage.	Suspended solids in original sewage. Parts per 100,000.	Suspended solids in tank liquor. Parts per 100,000.		Time of passage through tanks.
			Average.	*Remarks.*	
Accrington	Strong domestic sewage	38·93	19·40	14·3 shortly after sludging	Once in 42 hours.
Andover	Domestic, containing some brewery refuse.	15·80	11·10	8 months after incomplete sludging.	Once in 19·3 hours (dry weather flow). Once in 13·1 hours (max. flow).
Caterham	Exceptionally strong domestic	42·10	22·2	1 month after sludging	Apparently 48 hours' flow, when 3 out of the 4 hourly sets were drawn.
Exeter (Main Works)	Strong domestic	37·2	12·50	18 months after sludging	Once in 11·5 hours (dry weather flow).
Exeter (St. Leonards)	Weak domestic	26·10	8·40	12 months after complete sludging.	Once in 17·8 hours (dry weather flow). Once in 8·6 hours (maximum flow).
Hartley Wintney	Domestic, with a considerable proportion of brewery refuse.	20·10 (dilute winter sewage) 32·7 (dry summer sewage)	15·10	After 3½ years without sludging	Once in 31·7 hours (dry weather flow).
Guildford	Strong domestic, containing a large proportion of brewery refuse.	42·1	15·9	Tank full of sludge	Once in 36·7 hours.
Knowle	Domestic	19·40	8·42	—	Once in 15·2 hours (dry weather flow). Once in 3·2 hours (max. flow).
Prestolee	Weak slopwater sewage	5·42	3·17	After 4½ years without sludging	Once in 22 hours (dry weather flow).
Rochdale	Strong manufacturing sewage, containing large quantity of wool scourings, etc.	36·70	5·30	Tank in use for only 3 months	Once in 30 hours.
Slaithwaite	Dilute domestic (mainly slopwater)	10·70	7·10	After 5½ years without sludging	Once in 13·6 hours (dry weather flow).
York	Weak domestic	21·2	5·3	Two tanks, one in use 18 months and the other 6 months.	Once in 26 hours.

It must also be observed that it is generally impracticable to maintain the amount of suspended solids issuing from a septic tank at an approximately uniform level for any length of time; and, that the amount has a tendency to increase seriously as time goes on.

For example, at Burnley it was found that the suspended matter varied from 15 parts per 100,000, after a few weeks' working, to 35 parts per 100,000 at the end of six months; at Huddersfield the amounts were 6·6 parts per 100,000 at the commencement and 23·3 parts per 100,000 at the end of eleven months; at Leeds, from January to June, 1903, starting with a perfectly clean tank, the suspended solids averaged 12·2 parts per 100·000, and from July to December, 1904, the average was 24·1.

The variation in the amount of the suspended solids in the tank liquor increases the difficulty of maintaining the effluent from the filters at a constant level of purity, and the amount of tank liquor which can be properly dealt with on the filters tends to decrease as the amount of the suspended solids in the tank liquor increases.

Cleansing of Septic Tanks.

38. There is no doubt that the longer a tank is run without cleaning, the less *volume* of sludge there will be per million gallons of sewage treated. Digestion, of course, plays some part in this, but only a small part compared with the settling together of the finely divided septic sludge lying at the bottom of the tank. The sludge from a septic tank which is cleaned out at short intervals of time may contain something like 90 to 95 per cent. of water, while, if the tank is allowed to run for, say, two years, the water in the sludge may be only 80 to 85 per cent., or even less. It is obvious that this makes a great difference in the volume of the sludge to be dealt with, provided that it can be removed from the tank in the semi-solid form and without having to be mixed with sewage or water to make it run through the valves.

There is also evidence to show that sludge which has remained in a tank for a long period, say, a year or more, is in some cases less offensive than sludge which has been there for only two or three months. At Birmingham, Leeds, Exeter, and other places this was found to be the case, though, on the other hand, at Guildford, where there is a considerable amount of brewery waste in the sewage, the septic sludge had a very offensive smell when removed from a tank which had been in operation for a period of twelve months.

39. From the point of view of sludge disposal alone, it would be generally advisable to allow septic tanks to run for considerable periods of time before cleaning out, either wholly or partially. There are, however, two other important considerations to be taken into account, viz.:—

The amount of suspended matter issuing in the tank liquor, which greatly increases as time goes on, and

The fact that at a large sewage works it would usually be less easy to deal with very large quantities of sludge at long intervals of time than with smaller quantities at short intervals.

Constant conditions as regards the amount of suspended solids in the liquor issuing from the tank should be aimed at, and from this point of view frequent partial removal of the solids would usually be desirable; but our experience points to the conclusion that there can be no definite rules as to how long a septic tank should be run without cleaning, and that it must be left to the manager of each works to see that the suspended solids issuing from the tank do not increase to such an extent as to have an injurious effect upon the filters or upon the quality of the filtrate. The point at which injury to the filters or deterioration of the filtrate will occur will largely depend upon the nature and strength of the sewage, the kind of filter used, the size of the material in the filter, and the rate of filtration. At Accrington, for instance, something like fifteen parts of suspended matter in the septic tank liquor can be put upon the coarse percolating filters, without any danger of clogging, whereas at Manchester and Burnley, this would be too much for the contact beds.

Again, the successful working of some forms of fine percolating filter (*e.g.*, that at Friern Barnet), depends upon the time allowed for the drying of the sludge on the surface of the material between two applications of tank liquor. A tank liquor containing, say, 10 parts of suspended matter per 100,000, might be conveniently treated on a filter of this kind, if the delivery were made once every three days; but if it were made once every day, the sludge caught on the surface of the filter would probably not have dried sufficiently to allow of its being scraped off before the next delivery was made.

40. Although the point is not one in regard to which any general rules of a precise character can be laid down, we are inclined to think that in the case of small sewage works, constructed to serve populations of, say, 100 to 10,000, it would be best that septic tanks should be allowed to run, without being cleaned out, so long as the suspended matter in the tank liquor showed no signs of affecting the filters detrimentally, provided that the tanks were never allowed to become more than one-third full of sludge.

In the case of a sewage works constructed to serve populations from 10,000 upwards, we think it would probably be advisable partially to clean out septic tanks at short intervals of time, care being taken as far as possible to remove only the best digested portion of the sludge.

41. With regard to the question whether it is advisable *entirely* to remove the sludge from septic tanks when these are cleaned out, the evidence and our own observations seem to show that this is not advisable. Experiments at Leeds, Rochdale and Dorking have shown that the changes which sewage liquor undergoes in a septic tank are of minor importance as regards subsequent filtration, but the following considerations must be borne in mind:— Cameron, 1902; Harrison; Campbell; Valentine; Wilkinson; Raymond, Ross and Pickles; Watson; Harding; Fowler.

In a septic tank which is to be cleaned out there is always a considerable amount of sludge which has had little time to undergo digestion. If possible, therefore, this part of the sludge should be left in the tank.

One of the main uses of a septic tank is that it has the effect of equalising the sewage as regards strength, and of keeping the character of the liquor uniform.

If a septic tank is cleaned out completely, some weeks may pass before the fermentation of the sludge is in full progress again. It was found, at Birmingham, that, if some of the sludge is left in a septic tank at the time of cleaning, fermentation is hastened when the tank is re-started. At Rochdale, Mr. S. S. Platt has shown that the same effect can be produced by filling a clean and empty tank with septic liquor (from another tank) before any fresh sewage is allowed to pass into it.

Where sludge is removed from septic tanks at long intervals of time, and especially where it is disposed of by burial in the ground, it is of great importance to carry out the operation in dry weather. The success of the plan of disposing of the sludge by burial in the ground depends very largely upon the rapidity with which the sludge can be covered over in the trenches, and this is governed by the state of the ground and the atmospheric conditions prevailing at the time.

Rate of Flow through Septic Tanks.

42. For the reasons which we have already given we consider that the main objects in passing sewage through septic tanks must be looked upon as being:—

The settlement of the suspended matter in the sewage;

The digestion of as much sludge as possible; and

The equalisation of the sewage as regards strength.

43. The most advantageous rate of flow, therefore, is that which gives the maximum settlement and the maximum digestion of sludge, without producing any serious nuisance from smell. It is impossible, however, to lay down any given rate or rates of flow through septic tanks for all sewages, for the following reasons :—

The suspended matter in sewage differs as regards ease of settlement and rate of fermentability at different places. The suspended matter in a strong slopwater sewage, for instance, settles more easily and takes longer to putrefy than the suspended matter in a strong domestic sewage derived from water-closets.

The degree of settlement depends also upon the form of tank adopted. The passing of a sewage through a Dortmund tank, for instance, would no doubt give better settlement than would be the case if a plain rectangular tank were used, but there would probably be less digestion of the sludge.

The qualities necessary in the septic tank liquor may vary at different places. At one place where septic liquor was to be treated upon percolating filters of coarse material, a larger quantity of suspended matter might be allowed to pass away in the liquor, without danger to the filters, than at another place where the liquor was to be treated upon fine-grained filters. Again, where it was of the utmost importance to have as little sludge to deal with as possible, and where the filters could be washed and re-made cheaply, the digestion of the sludge would be of greater importance than the settlement of the suspended matter; whereas, at another place where ample facilities for dealing with sludge existed and where filtering material could only be obtained at high cost, the reverse would be the case.

The question of smell arising from the septic liquor during its distribution would also assume greater or lesser importance at different places. Generally speaking, very slow passage through the tank tends to increase the risk of nuisance from smell.

In a number of cases, owing to long sewers or to the use of the sewers for storage, the sewage is already in what is called a "septic" condition when it reaches the sewage works.

44. The rate of flow through a septic tank is consequently a matter in which the needs of each place require to be taken into account: but from general experience and a consideration of the evidence, we think it may safely be said that at few places should the sewage remain more than 24 or less than 12 hours in a septic tank. We think therefore, that the total tank capacity, excluding the stand-by * tanks for storm water, should be equal to the total daily dry weather flow. In designing a sewage works where septic tanks were to be adopted, never less than two tanks should be provided, and these should be so constructed that one tank alone could be used at a time. If better settlement became necessary, it might be found that this could be effected by using the tanks in series and adding small quantities of some precipitant to the liquid as it passed into the second tank.

21992. 45. Colonel T. W. Harding and Mr. W. H. Harrison carried out a series of experiments at Leeds, in which flows sufficient to fill the septic tanks in 12, 24, 48, and 72 hours were compared. The results showed that at that place, and using simple rectangular tanks, a rate of flow sufficient to fill the tank once in 24 hours was the best economic rate. Rates of flow slower than this gave only slightly better results as regards suspended matter in the tank liquor, and greater rates of flow brought out more suspended matter than it was thought desirable to send on to the filters. The experiments showed also that; if the flow was increased to a rate which filled the tank in 12 hours, the tank

* As to "stand-by" tanks see section dealing with treatment of storm water sewage, p. 204.

became choked with sludge before septic action was induced. The figures of analysis for the different rates of flow are given in the Report on Experiments in Sewage Disposal, City of Leeds, June, 1905, p. 66, as follows :—

Average Analyses referring to the effect of different rates of flow through open Septic Tanks.

Grains per gallon.	12 hours' flow.		24 hours' flow.		48 hours' flow.		72 hours' flow.*	
	Average analysis.	Per-centage reduction on crude sewage.	Average analysis.	Per-centage reduction on crude sewage.	Average analysis.	Per-centage reduction on crude sewage.	Average analysis.	Per-centage reduction on crude sewage.
Total solids	87·7	—	78·2	—	78·6	—	73·9	—
Suspended Solids	19·2	52	11·4	71	10·9	73	9·9	76
Free Ammonia	1 56	·22	1·51	24	1·62	19	1·79	37
Albuminoid Ammonia	0·54	50	0·45	58	0·38	64	0·34	52
Oxygen absorbed in 4 hours at 80° F.	5·21	45	4·84	49	4·30	55	3·59	55

* Experiment at later date with weaker sewage.

46. Dr. G. J. Fowler, in his evidence relating to Manchester (May 12th, 1905; answer to Question 22773), says :—

"The most advantageous rate of flow is largely a matter of circumstances. It may be roughly taken from available experience that, with sewage of a strength of 40 gallons per head, about 24 hours' flow is desirable; with a greater flow per head (the organic matter remaining the same) the rate may be correspondingly quicker and, with a less flow, less. Our knowledge on this subject is very imperfect. One may say, at any rate, that time must be given for settlement of the grosser solids and hydrolysis of the lighter suspended matter. Much, of course, depends on the length of travel in the sewer; with a long travel the simple hydrolytic changes will already be almost complete, whereas, on the other hand, in latrine sewage the matter entering the tank may be practically in its original condition. There can be little doubt that the chief activity of the septic tank resides in the sludge and this needs to remain in the tank a very long time for thorough digestion to take place."

In answer to a further question (22979), Dr. Fowler stated that 24 hours' stay in the tank is the longest time he would allow.

Messrs. Watson and O'Shaughnessy, in their evidence relating to Birmingham (May 18th, 1905; answer to Question 24983), say :—

"The actual mean rate of flow through the first set of tanks is ·87 feet per minute, and through the second set of tanks ·32 feet per minute. This rate of flow is sufficient to set up most vigorous fermentation, and results in the destruction of very considerable quantities of organic matter, as evidenced by the copious evolution of gas from the tanks, and by the increase in the amount of 'free ammonia' in the tank liquor. A quicker rate of flow is detrimental to the septic action. The action is continued in the large conduit, the liquor taking something like 6 hours to traverse it. At the end of the conduit is a Dortmund tank installation, and here we have been able to make some interesting observations on the behaviour of this already highly septic liquor. We consider that septic treatment of Birmingham sewage for a period of at least 24 hours to be distinctly advantageous. At the present time this is as much as we can say definitely. The observed effect of additional septic treatment at the end of the conduit, in the Dortmund tank, is a great increase in the number of micro-organisms in the tank liquor. We consider that the rate of flow should depend very largely on the strength and on the character of the particular sewage to be dealt with—a stronger sewage requiring a longer time, and certain constituents of sewage being more easily broken down than others."

47. As regards the question whether it is possible to "over septicise" a sewage, several witnesses have stated that if sewage be kept too long in the tank, the amount of sulphuretted hydrogen produced is considerably increased, and some witnesses have expressed the view that too long a stay tends to impair the subsequent oxidation of the sewage during its passage through the filters.

Should Septic Tanks be closed or open?

48. We are not aware that any comparative observations have been made of the relative merits of closed and open tanks in the case of a domestic sewage, but comparative experiments have been carried out at Birmingham, Burnley, Leeds, and Manchester, which show that, as regards digestion of sludge and quality of tank liquor, the closed tank possesses no advantages over the open tank.

49. In cases, however, where it is important to avoid nuisance from smell, our experience shows that the closed tank is generally preferable.

At Exeter, Yeovil, Andover, Hartley Wintney, and Prestolee, where the tanks are covered in, the smell from the tanks themselves is almost entirely done away with.

At Accrington, Leeds, Rochdale, and Burnley, where the tanks are uncovered, there is, as a rule, appreciable local smell.

At Sheffield, the nuisance arising from the open (experimental) septic tank was so pronounced, that the men on the works raised strong objections.

At Gosport, a very serious nuisance arose from open septic tanks, which was almost entirely done away with by completely roofing over the whole of the tanks and channels at the works.

At Guildford and Carshalton it was found necessary to put a rough covering over the tanks. In both cases the smell was largely diminished as the result.

At Ilford, a substantial roof is now being provided, to diminish the smell.

On the other hand, at Birmingham and Manchester, very little smell arises from the open septic tanks. This is no doubt accounted for by the fact that the sewages contain manufacturing waste, iron salts in the case of Birmingham, and iron salts and tarry matter in the case of Manchester.

50. As regards closed tanks, we may observe that a roof somewhat hampers sludging operations, and further, that care is necessary to avoid explosion of the gas which accumulates under the roof. Serious accidents have been caused by the explosion of the gas in closed septic tanks.

Arrangements for removing Suspended Solids from Septic Tank Liquor before it is delivered to the Filters.

51. So far as we know, none of the attempts to screen septic tank liquor by passing it through a short depth of material have been successful. At Leeds a layer of fairly fine material was suspended in a small septic tank in such a way as to cause the liquor to pass through it before leaving the tank. The sludge lying at the bottom of the tank, in rising to the surface as a result of the evolution of gas completely clogged the bottom of this material and rendered it worse than useless for screening purposes.

At Ilford and Guildford layers of coarse material have been placed at the outlet sills of the tanks, but it appeared to us that this arrangement was ineffective.

At Chester a plan similar to that tried at Leeds was followed, but after a short time the straining material became seriously choked with the suspended matter rising from the bottom of the tank. The tank liquor consequently forcing its way to the surface through special channels, bringing a great deal of suspended matter with it.

52. At Salford, *precipitation liquor* is forced by head of water (5′ 6″) through a layer of medium to coarse gravel (½ to 1½ inches diameter), three feet in depth, laid at the bottom of some specially constructed tanks, called "Roughing filters." This plan undoubtedly removes a very considerable quantity of the suspended matter from the precipitation liquor. The area of these "Roughing filters" is, however, so small compared to the volume of precipitation liquor to be passed through them, that they can only deal with two-thirds of the flow, the gravel being almost always more or less clogged. About 8,000,000 gallons of precipitation liquor are, on the average, forced through the "Roughing filters" per day, and as the total area of filtering material in the tanks is only 2,040 square yards, the average rate of filtration is roughly 4,000 gallons per square or per cube yard per day. The material in the "Roughing filters" at Salford is washed by upward flow once in every six days, each filter working for five days and resting for one. Once a year the gravel is taken out and thoroughly washed. The average analysis of the Salford precipitation liquor, after it had passed through the roughing filters, is given by Mr. J. Carter Bell, as follows:— Bell, 23207.

1903 and 1904.

	Parts per 100,000.
Oxygen absorbed from permanganate in four hours	4·7
Alkalinity as calcium oxide	3·0
Free and saline Ammonia	1·95
Albuminoid Ammonia	·45
Nitrogen as Nitrates and Nitrites	·172
Chlorine	14·1
Suspended solids	2·9

Mr. Carter Bell stated that it has been found practicable at Salford to remove about 75 per cent. of the suspended matter of the precipitation liquor by means of the roughing filters. 23225

53. At Friern Barnet the precipitated sewage is given a two hours' contact in contact beds, called roughing filters, before it passes to the low level percolating filters. These roughing filters consist of medium-sized clinkers, four feet nine inches in depth. They remove a considerable portion of the suspended matter from the precipitation liquor, and may be looked upon as primary contact beds.

Straining tanks of a somewhat similar kind have been in use at Wimbledon for a number of years. In these, however, the filtering material (three feet in depth) rests on a false bottom, some distance from the bottom of the tank, and the sewage entering at the bottom of the tank flows upward through the material, a large portion of the suspended matter settling upon the floor of the tank underneath the material. The tanks are cleaned at short intervals of time. We believe the plan has been found to work well.

54. At Birmingham Mr. J. D. Watson interposes modified Dortmund tanks between the septic tanks and the continuous filters. He states that the average of nearly a year's observations shows that the Dortmund tanks removed 75 per cent. of the suspended matter from the Birmingham septic tank liquor. It must be remembered, however, in regard to this, that the Birmingham septic tank liquor contained a large quantity of suspended matter, the average amount for the year 1904 being 19·5 parts per 100,000. If Dortmund tanks were used for the settlement of tank liquors containing only small quantities of suspended matter (say five parts per 100,000), they would, we think, probably not be as efficient as some straining method such as that adopted at Salford. Watson, 25001.

55. A special tank has been designed by Dr. Owen Travis for the further removal of suspended and colloidal matter from the septic tank liquor at Hampton. We have not, ourselves, been able to make any observations on this tank.

Lime Precipitation following Septic Tank Treatment.

56. From some experiments which we have carried out at Dorking, we find that, by passing septic tank liquor through tanks of a size sufficient to hold about one quarter of the 24 hours flow, with the addition of from 2 to 3 grains of lime per gallon

to the liquor, the suspended solids are reduced from 8 to 5 parts per 100,000, a considerably larger quantity of the liquor can be purified per cube yard of filter, and the offensive character of the septic tank liquor is largely destroyed. The solids which are chiefly reduced are those which are volatile.

In many cases we think that this combination of septic tank treatment and precipitation will be found to be useful.

We have, however, had no experience of this arrangement on a large scale.

A small quantity of lime (about 1 grain per gallon) has been added to the septic tank liquor at Blackburn for some years with a view to aiding subsequent nitrification on the filters.

Chemical Precipitation.

57. There has been a tendency on the part of certain authorities to regard the chemical precipitation of sewage as an obsolete form of preliminary treatment. Our experience in no way justifies this view, and while we are not able to lay down any precise rules as to the particular cases in which chemical precipitation should be adopted, nor as to the relative cost and efficiency of the various precipitants which are available, we think it may be useful to state generally the results of our observations.

In the case of some sewages, which contain trade waste, it is almost essential to subject the sewage to some form of chemical treatment before attempting to oxidise the organic matter contained in it, and in the case of domestic sewages, chemical precipitation materially aids the deposition of the suspended solids, and facilitates subsequent filtration.

58. The actual amount of suspended solids remaining in the sewage after chemical precipitation varies according to a number of factors, but in the case of a domestic sewage, which is allowed to stand and settle for about 2 hours, it is practicable to produce a tank liquor containing from 1 to 4 parts per 100,000. Where the settlement is effected by continuous flow through the tank, at an 8-hour rate, the suspended solids may be brought down to from 3 to 6 parts per 100,000.

59. Excepting for the results relating to the Dorking sewage, which are given below, we have ourselves made no comparative experiments with regard to the relative cost and efficiency of the various substances used for the precipitation of sewage. We have, however, had some experience of the following precipitants, at works which have been under our observation :—

Lime.
Lime used in conjunction with Copperas (Ferrous Sulphate).
Lime used in conjunction with Alumino-ferric.
Alumino-ferric.
Alumino-ferric used in conjunction with blood, charcoal and clay (A.B.C. process).
Ferrozone.
Ferric Sulphate.
Sulphuric Acid.

At most of the works where domestic sewage has been treated, alumino-ferric has been the precipitant used. At some of the works, this precipitant has displaced ferrozone on the score of economy, and at Chorley, a considerable saving in cost (about £1 per million gallons) was effected by the manufacture of alumino-ferric upon the works.

At Dorking, although we did not experiment with equal aggregate quantities, the results of a series of experiments led us to the conclusion that a better result was obtained from a mixture of lime and alumino-ferric than from alumino-ferric alone.

The same conclusion, we believe, resulted from experiments made by Mr. Creer, the City Engineer of York, with the sewage of that city. Owing to its low solubility in water, lime requires automatic machinery for crushing and mixing before it can be effectively added to the sewage, and for very small sewage works its use would not be economical.

60. The following table gives a list of places where domestic sewage alone, or mixed with small quantities of trade refuse (as a rule brewery or tannery waste), is precipitated, the quantity of precipitant used, the dry weather flow of sewage, and the cost of the precipitant :—

TABLE I.

Place.	Precipitant.	Quantity of precipitant added (in grains per gallon). Based on the dry-weather flow.	Dry weather flow of sewage (treated by the precipitation process).	Character of Sewage.	Cost of precipitant per million gallons. Based on dry-weather flow.	Cost of precipitant per million gallons. Based on average daily flow.	Year.
			Gallons.		£ s. d.	£ s. d.	
Withnell -	Alumino-ferric -	15·7	10,000	Very strong	5 6 0		1903.
Radcliffe -	Alumino-ferric -	8·0	800,000			2 15 0	1902, 1903, 1904 & 1905.
Calverley	Alumino-ferric -	17·5	12,000	Very strong	2 10 0		1904.
Heywood -	Alumino-ferric - Ferrozone - -	8·0 8·0	630,000 630,000	Average strength.		1 7 6 1 6 6	
Guildford -	Alumino-ferric -	8·0	300,000	Very strong	2 2 0	1 4 5	1905.
Horfield -	Alumino-ferric -	5·0	40,000	Average strength.	1 10 0	0 17 6	1905.
Normanton -	Alumino-ferric -	6·7	175,000	Very strong	1 5 0		1902 to 1905.
Hendon	Alumino-ferric -	5·5	950,000	Rather strong.		0 13 3	1906.
Chorley -	Alumino-ferric -	9·0	900,000	Average strength.		0 12 10	1902.
Royton -	Alumino-ferric -	2·22	367,500			0 6 7½	1906.
Buxton	Natural Iron-water - Milk of Lime -	6–7 6 } 12 to 13	750,000			0 4 6	1906.
Dorking -	Lime - - Alumino-ferric -	5·6 3·5 } 9·1	200,000	Average strength.		0 15 8	1902, 1903 & 1904.
Friern Barnet	Lime - - Alumino-ferric -	4·0 2·0 } 6·0	350,000		Lime 5/1 Alumino-ferric 7/7½ } 0 12 8½		
York - -	Lime - - Alumino-ferric -	5·77 4·3 } 10·0	3,750,000	Average strength, or perhaps under average.		0 10 7	1904–1905.
Willesden -	Lime - - Alumino-ferric -	3·85 5·46 } 9·31	1,930,950		Lime 1/5·38 Alumino-ferric 8/6·5 } 0 10 0		
Ealing -	Lime - - Alumino-ferric -	4·0 2·0 } 6·0	1,000,000			0 6 9	Three years ending March, 1906.
Leyton -	Lime - - Hanson's Sulphurous Powder - -	15·0 7·0 } 22·0	3,000,000			3 11 0	1905–1906.
Kingston -	Alumino-ferric, blood, charcoal, and clay (A.B.C. process) - - -	50·0	2,750,000	Average strength.		3 4 0	1902, 1903 & 1904.
Rochdale -	Alumino-ferric - Sulphuric Acid -	7·3 4·7 } 12·0	2,000,000	Very strong		1 8 7	1904–1905.

Note.—It will be observed in the above table that at nearly all the places where lime is used as a precipitant the cost is relatively low. In regard to this, however, it must be stated that the figures of cost refer to the lime alone and do not include any charges with respect to the mixing. This might add, we think, from 2/– to 10/– per million gallons, according to circumstances.

61. In Table II. some of the places where we have made special observations are arranged in the order of percentage reduction in suspended matters. The figures for Withnell and Calverley are not included, the flow of sewage at those places being too small for proper comparison with the others.

TABLE II.

Place.	Precipitant.	Percentage reduction of suspended matter in the crude sewage.	Amount of precipitant added in grains per gallon. Based on dry-weather flow.	Actual amount of suspended matter left in the precipitation liquor (parts per 100,000).	Cost of precipitant alone per million gallons, based on the average daily flow.	Strength of precipitation liquor calculated on the basis suggested by Dr. McGowan, *see* p. 16.	Strength of crude sewage calculated in a similar manner.
					£ s. d.		
Kingston -	Alumino-ferric, blood, charcoal, and clay (A.B.C. process)	95	50·0	1·5	3 4 0	51	94
Horfield - -	Alumino-ferric	93	5·0	2·5	17 6 (approx.)	36	88
Chorley - -	Alumino-ferric	91	9·0	2·9	1 0 2*	50	106
Heywood -	Alumino-ferric	82	8·0	5·0	1 7 6	42 (approx.)	
Dorking - -	Lime -	82	9·0	7·0	15 8 (approx.)	about 60	95
Hendon - -	Alumino-ferric	80	5·5	5·5	13 3	58	110
Rochdale - -	Alumino-ferric and sulphuric acid	79	12·0	7·8	1 8 7	77	203
Guildford -	Alumino-ferric	75	6·5	14·6	1 4 5	171	194
Normanton -	Alumino-ferric	67	6·7	18·0	1 5 0	112	235
York - -	Lime and alumino-ferric	64	10·0	7·7	10 6	63	115

62. In comparing the costs in Table II., the influence which the suspended matter left in the liquor has upon the life of the filter-beds, used subsequently, must be specially borne in mind. For instance, according to their calculated strengths, the Kingston and Chorley precipitation liquors would require about equal filter areas, but the Kingston liquor only contains 1·5 parts per 100,000 of suspended solids against 2·9 parts in the Chorley liquor, and on the assumption that the rate of clogging is broadly in proportion to the amount of suspended matter in the liquor treated, if the two liquids were treated upon equal areas of *contact* beds, the filtering material would require washing twice as often at Chorley as at Kingston. The amount of colloidal matter is not great in either liquor.

The A.B.C. process is, undoubtedly, a very efficient form of chemical precipitation, and the dried sludge produced at Kingston is sold by the company.

In regard to all tank processes, it may be remarked that the greater the amount of suspended matter in the original sewage, the easier it is to obtain a good *percentage* reduction of the suspended solids.

* This figure applies to the year 1900, when the alumino-ferric was bought. At the present time (1906), when the alumino-ferric is made on the works, the cost of precipitation per million gallons is 12*s.* 10*d.*

63. In the experiments carried out under the Massachusetts State Board of Health, Mr. Allan Hazen compared lime, lime and ferrous sulphate, ferric sulphate and aluminum sulphate as used in various quantities upon the St. Lawrence sewage during the year 1889 (Report of experiments upon the chemical precipitation of sewage. State Board of Health, Massachusetts, 1890). The sewage was a very weak one.

The following are quotations from the summaries given in the Report by Mr. Hazen on these experiments:—

The Comparative Advantages of the Different Precipitants.

"It does not seem to me that the slight colour given by the use of iron "should be considered an objection in judging the merits of the different "processes. It should be remembered that when alum is used, a small "portion of the alumina is really present in the effluent, but being white, it "is not noticed as is a corresponding amount of iron.

"The lime process has little to recommend it. Owing to the large amount "of lime-water required and the difficulty of accurately adjusting the lime to "the sewage, very close supervision would be required to obtain a good "result, and, even then, the result is inferior to that obtained in other "ways.

"Precipitation by copperas is also somewhat complicated, owing to "the necessity of getting the right amount of lime mixed with the sewage "before adding the copperas. When this is done, a good result is obtained. "The amount of iron left in the effluent is much greater than the ferric "sulphate owing to the great solubility of ferrous hydroxide.

"Ferric sulphate and alum have the advantage over both lime and "copperas, that their addition in concentrated solution can be accurately "controlled, and the success of the operation does not depend upon the "accurate adjustment of lime or any chemical to the sewage. The results "with ferric sulphate have been, on the whole, more satisfactory than those "with alum. This seems to be due in part to the greater rapidity with "which precipitation takes place and in part to the greater weight of the "precipitate. It is probable, from the greater ease with which ferric "sulphate is precipitated, that it would give a good result, with a sewage "that was not sufficiently alkaline, to precipitate alum at once. It is quite "possible that the same process would not give equally good results upon "all kinds of sewage. Special sewages may require special treatment. "For this reason, and also on account of changes in the prices of the several "chemicals, it is impossible to say that one precipitant is universally better "than another."

Conclusions.

"Using equal values [*i.e.*, as regards price] of the different precipitants, "applied under the most favourable conditions for each, upon the same "sewage, the best results were obtained with ferric sulphate. Nearly as "good results were obtained with copperas and lime used together, while "lime and alum each gave somewhat inferior effluents. The range of these "results was, however, comparatively narrow; and it may be that with a "sewage of a different character, or with variations in the prices of the "chemicals, it would be advantageous to use copperas with lime, or even "alum. When lime is used, there is always so much lime left in solution "that it is doubtful if its use would ever be found satisfactory except in "case of acid sewage."

64. Various comparative experiments with precipitants have been made at a number of large towns and cities in this country; for instance, at Glasgow, amongst other experiments of the same kind, Mr. Thomas Melvin has experimented with sulphate of alumina and ferric sulphate, both used in conjunction with lime. The sulphate of alumina (44·5% $Al_2(SO_4)_3$), which was bought, cost 33s. per ton, while the ferric sulphate (9% Fe), made upon the works, cost 11s. 3d. per ton. In each of the trials (which extended over long periods) 8 grains per gallon of the precipitant were used in conjunction with 4 grains per gallon of lime. We understand that ferric sulphate and lime always gave the better result.

Sir Thomas Wardle ("Sewage Treatment and Disposal") also obtained good precipitation results by the use of a mixture containing basic ferric sulphate as its chief ingredient.

Fowler, 22758. In his evidence relating to Manchester Dr. G. J. Fowler stated:—

"I have had experience with various chemicals, viz., lime and copperas, "ferric salts and alumino-ferric, but have not gone very exhaustively into "their various merits. Lime and copperas give a precipitate which readily "settles, and lime is useful where flushes of acid have to be neutralised. On "the other hand, their use requires constant and skilled supervision, and "is therefore less suitable for small works than alumino-ferric, where a given "quantity can be added from time to time and be left to dissolve in the "incoming sewage. Ferric salts I have not found to give so rapid pre-"cipitation as either the lime and copperas or the alumino-ferric. The "precipitate appears more finely divided than either of the others. More-"over, ferric salts, unless made on the works, are not readily obtained in "the quickly soluble and, at the same time, transportable condition. The "following are prices per ton delivered at or near Davyhulme, showing that "for equal weights, lime and copperas are undoubtedly cheaper than "alumino-ferric:—

"Lime	11s. 6d.
"Copperas	21s. 6d.
"Alumino-ferric	40s. 0d.
"Ferric sulphate	23s. 6d.

"These prices will, of course, vary in different parts of the country."

Watson 24968. Mr. J. D. Watson and Mr. F. R. O'Shaughnessy, in their evidence relating to Birmingham, stated:—

"Milk of lime added to the crude sewage was used as a chemical "precipitant for many years, and was totally discontinued in February, 1901. "During the last twelve months of this process the tank capacity at the out-"fall works consisted of two installations of tanks, which were worked in "series. The mean period of sedimentation in the preliminary tanks was "3½ hours, and in the secondary installation of tanks the mean period of "sedimentation amounted to 5½ hours, giving a total mean period of "sedimentation for the limed crude sewage of 9 hours. The flow of sewage "for the last twelve months of the process was estimated at twenty million "gallons per day. The proportion of lime added to the crude sewage was "12 grains per gallon, being the equivalent to a quantity of 15 tons 6 cwts. "dry lime used daily.

"The following analysis will indicate the effect of this liming process "upon the crude sewage:—

Year 1900.	Parts per 100,000.	
	Dissolved Solids.	Suspended Solids.
Crude Sewage - - - - - -	129·1	67·6
Preliminary Tank Liquor - - -	138	16·3
Final Tank Liquor - - - - - -	133·2	4·2*

Harrison, 21979. Mr. Harrison, in his evidence relating to Leeds, stated:—

"Several precipitants have been tried upon the Leeds sewage in order "to obtain their relative values, but the question of cost has not been

* It must be borne in mind that the Birmingham sewage contains iron salts in considerable quantity, so these good results cann t be ascribed to the lime alone.

"considered. The most effective precipitant was a mixture of ferric salt and "lime, closely followed in merit by aluminum sulphate and lime. These two "precipitants were almost equally effective, and were followed in order of "merit by alum and lime, ferrous sulphate and lime, ferric salts, alum and "ferrous sulphate. The last was practically valueless."

Mr. Carter Bell in his evidence relating to Salford, stated:— Bell, 23218.

"We have tried many systems of sewage purification and combinations "of chemicals. The best and most economical results have been obtained by "the use of lime followed by salts of iron."

Mr. Bolton, in his evidence relating to Heywood, stated:— Bolton, 21107.

"I have tried various chemicals. Iron and alumina compounds have "been used under such trade names as alumite, kremnolite, ferrozone, "alumino-ferric, etc. Alumino-ferric is the best precipitant tried at "Heywood. With an addition of 8 grains per gallon, a purification of "62 per cent. is brought about. This equals £1 7s. 6d. per million gallons. "Ferrozone under the same conditions brought about a purification of 57 "per cent., equal to a cost of £1 6s. 6d. per million gallons. Thus, for 3·6 "per cent. reduction in price 8 per cent. less purification was obtained "by ferrozone."

65. Where the sewage, by reason of the discharge of large quantities of trade refuse, is of a special character, special precipitants have, of course, to be used.

At Bradford, where there is a very large proportion of wool-scouring refuse in the sewage, sulphuric acid is used as the precipitant, in order to separate the fat, which is afterwards extracted from the sludge.

At Rochdale, where on several days of the week, owing to the discharge of wool-scouring refuse, the sewage resembles that of Bradford, sulphuric acid is used to neutralise the alkali in the wool-scouring refuse *after* the precipitation of the sewage with alumino-ferric.

At Burton-on-Trent, where there is a largely preponderating quantity of brewery waste in the sewage, very large quantities of lime have to be added.

Ways of adding chemicals.

66. Chemicals are most effective in precipitating a sewage when they are added in the form of a solution.

In practice, however, the addition of a solution of precipitant to a sewage is not always so economical or effective as the use of the precipitant in a solid form, owing to the fact that it is advisable to vary the quantity of the solution with the varying strength of the incoming sewage—a matter of some difficulty at a small works.

At a large works, where the addition of the chemicals can be properly supervised, we should think that, with the exception of lime, all chemicals should be added in the form of a solution. Lime is best added in the form of milk of lime, as it is not very soluble in water, and its addition in solution, involves the use of large quantities of water or sewage.

At medium-sized or small works it is usually found best, for economy of labour, to add such precipitants as alumino-ferric or ferrozone in the form of a solid block, placing the block in the sewage channel so that the top of it projects above the level of the sewage. In this way the largest quantities of precipitant are dissolved at those times of the day when the flow of sewage is greatest.

67. At Horfield and Hendon we found a simple and effective way of adding alumino-ferric in the form of a solution. The quantity of precipitant required for about 24 hours was, each morning, put into a box with a false bottom, and the alumino-ferric was dissolved by allowing water to drip on to it. During the daytime, when the box was full of precipitant, and when the sewage was strongest, a larger amount of the alumino-ferric was delivered to the sewage, owing to the solution being then stronger than it was at night, when almost all the precipitant had dissolved away. Moreover, the dose could be varied at will by increasing the flow of water.

This plan appeared to us to be rather more effective than the method of placing blocks of the precipitant in the sewage channels, though that method is also in the main satisfactory.

We have had no experience of copperas used alone; in the cases that have been brought to our notice, it has been used along with milk of lime. In these cases it has usually been found best to add it after the lime.

Immediately after the addition of any chemicals the sewage should be churned up so as to produce a thorough mixture. This can be done effectively by some mechanical apparatus or by baffling boards.

Some Observations as to the Relative Cost of various Preliminary Processes.

68. Local conditions and circumstances must always be the first consideration in the selection of a process for the preliminary settlement of the sewage of any particular place, and it is not possible to give figures of cost which would apply generally.

We think, however, it will be useful to compare the various processes in common use in a hypothetical case in which we assume:—

That ample fall is available;
That the sewage is of a normal domestic character and of average strength;
That the flow of sewage is 1,000,000 gallons per day in dry weather;
That all tanks are of simple construction, and rectangular in shape.

The processes which we propose to compare are:—

Septic tanks;
Continuous flow settlement without chemicals;
Quiescent settlement without chemicals;
Continuous flow settlement with chemicals;
Quiescent settlement with chemicals.

Comparative Capacities of Tanks.

69. From our general experience and from a consideration of the evidence we think the various lengths of time required for settlement and the number of tanks may, for the purpose of this comparison, be those shewn in the following table:—

Preliminary Process (arranged in order of tank capacity).	Stay in Tanks.	Total Number of Tanks.	Number of Spare Tanks.	*Total Capacity of Tanks required (gallons).
Continuous flow settlement with chemicals	8 hours	8	2	444,440
Continuous flow settlement without chemicals	15 hours	8	2	833,333
Quiescent settlement with chemicals	2 hours	10	2	1,041,660
Quiescent settlement without chemicals	2 hours	10	2	1,041,660
Septic tanks	24 hours	6	1	1,200,000

* The tanks would be sufficiently large to deal with 3,000,000 gallons per day in times of storm.

Initial Cost of Tanks.

70. From these estimates of the total tank capacities, Mr. G. B. Kershaw, our Engineer, has prepared drawings for each preliminary process, from which he has taken out complete quantities, and prepared the following estimates:—

Preliminary Process (arranged in order of cost).	Constructional Cost of Tanks.
Continuous flow settlement with chemicals	£3,797
Continuous flow settlement without chemicals	£5,112
Quiescent settlement with chemical	£5,987
Quiescent settlement without chemicals	£5,987
Septic tanks (open)	£6,891

Cost of Chemicals.

71. Several different substances are used in practice for the precipitation of sewage, dependent to some extent on the kind of sewage to be dealt with. For the precipitation of domestic sewage of about average strength, however, alumino-ferric is by far the most common and we have adopted this precipitant in our hypothetical case. The average quantity of the precipitant used may be put at about 10 grains per gallon (or 14·3 parts per 100,000). The cost of alumino-ferric varies at different places; but taking it at £2 5s. per ton, the cost of chemicals work out at £523 15s. per year or £1 8s. 8d. per million gallons of sewage (dry weather flow).

Production of Sludge.

72. We think it may be taken that, on the average, domestic sewage contains about 35 parts of suspended matter per 100,000 in dry weather, and that 1,000,000 gallons of domestic sewage would, in dry weather, produce approximately 1 ton 11 cwt. of *dry* sludge, *i.e.*, sludge containing no moisture. Where the quantity of alumino-ferric added is not excessive, practically the whole of its alumina is thrown out of solution, and since there is considerable evidence to show that small quantities of dissolved or colloidal sewage matter are also precipitated, we may assume for the purposes of this argument that, in addition to the 35 parts of suspended matter in the sewage, something like 5 parts of additional solid matter* must be taken into account. We assume, therefore, that our hypothetical sewage, with its precipitant, contains $35+5=40$ parts per 100,000 of suspended matter as it enters the tanks. From this must be deducted the amount of suspended matter issuing in the tank liquor, and, from a large general experience, we estimate that the addition of 10 grains per gallon of alumino-ferric to our hypothetical sewage would produce a tank liquor containing on the average about 2·5 parts per 100,000 of suspended matter if quiescent settlement were adopted, and about 4·5 parts per 100,000 if continuous flow settlement were adopted. On this basis the dry solid matter left in the settling tanks as the result of these two preliminary processes would be as follows:—

	Parts per 100,000.
Chemical precipitation followed by quiescent settlement	$35+5-2\cdot5=37\cdot5$
Chemical precipitation followed by continuous flow settlement	$35+5-4\cdot5=35\cdot5$

73. With settlement of sewage without chemicals, we estimate that the quantity of suspended matter issuing in the tank liquor would be approximately 7 parts per 100,000 after quiescent settlement, and 10 parts per 100,000 after continuous flow settlement. The dry solid matter left in the tanks, therefore, would be:—

	Parts per 100,000.
Quiescent settlement, without chemicals	$35-7=28$
Continuous flow settlement, without chemicals	$35-10=25$

* Alumino-ferric contains roughly 50 per cent. by weight of $Al_2(SO_4)_3$. If the whole of the alumina were precipitated by the sewage 14·3 parts per 100,000 of alumino-ferric would thus give approximately 2 parts per 100,000 of dry Al_2O_3. To the alumina must be added the colloidal matter thrown down by the action of the alumino-ferric upon the sewage, and we have estimated this at approximately 3 parts per 100,000. The latter figure has, however, been obtained from a comparatively small number of analyses.

74. In the case of septic tanks the digestion of sludge must be taken into account, as well as the amount of suspended matter carried away in the tank liquor. The digestion of sludge from a domestic sewage may be put approximately at 30 per cent. of the total suspended matter entering the septic tank, and on the average the liquor issuing from the septic tank would contain 10 parts of suspended matter. On this basis, the amount of sludge left in the septic tank would be 35 - 10 - 10·5 = 14·5 parts per 100,000.

75. The production of sludge in our five preliminary processes of settlement would, therefore, be represented by the following figures :—

Preliminary Process.	Sludge left in Tanks (in parts per 100,000).
Quiescent settlement with chemicals	37·5
Continuous flow settlement with chemicals	35·5
Quiescent settlement without chemicals	28·0
Continuous flow settlement without chemicals	25·0
Septic tanks	14·5

Taking the average percentage of water in the sludges generally at 90, we obtain the following figures for the production of wet sludge by each preliminary process per 1,000,000 gallons :—

Preliminary Process.	Wet sludge (90 per cent. water) produced per million gallons of sewage (dry weather flow).
Quiescent settlement with chemicals	17 tons
Continuous flow settlement with chemicals	16 "
Quiescent settlement without chemicals	12 "
Continuous flow settlement without chemicals	11 "
Septic tanks	6·5 "

Cost of Labour.

(*a*) Disposal of Sludge.

76. The various methods of disposing of sludge are not in every case suited to each kind of sludge. Septic tank sludge, for instance, is rather difficult to press, being usually greasy. For the purposes of comparison we have selected the plan of shallow burial in the soil, as this method is for practical purposes equally well suited for the disposal of the sludge from each preliminary process.

For the burial of 1,000 tons a year of wet sludge (90 per cent. water), we estimate that one acre of land with soil of good or medium quality is necessary. On this basis the following areas would be required for the burial of the sludge from the various preliminary processes :—

Preliminary Process.	Quantity of wet sludge (90 per cent. water) produced per annum.	Area of Land required.
Quiescent settlement with chemicals	6,205 tons	6·20 acres
Continuous flow settlement with chemicals	5,810 "	5·81 "
Quiescent settlement without chemicals	4,380 "	4·38 "
Continuous flow settlement without chemicals	4,015 "	4·01 "
Septic tanks	2,372 "	2·37 "

The trenching of this land and the covering of the sludge would probably require the whole time of two men in the case of the two chemical precipitation processes and the quiescent settlement process, and one man in the case of the continuous flow settlement process.

In the case of the septic tank process additional labour would only be required when the tanks came to be cleaned out, say, twice a year. On the assumption that the services of some six men would be required for a fortnight on these occasions, we estimate that this would involve a labour expenditure of about £30 per annum.

Taking labourer's time at 21s. a week, and including one-third of the manager's time at a salary of £130 per annum, the labour cost in connection with the sludge trenching would be as follows :—

Preliminary Process.	Cost of labour and Supervision in connection with the Disposal of Sludge on the Land.	
	Per annum.	Per million gallons of sewage (dry weather flow).
	£	s. d.
Quiescent settlement with chemicals	152	8 4
Continuous flow settlement with chemicals	152	8 4
Quiescent settlement without chemicals	152	8 4
Continuous flow settlement without chemicals	98	5 4
Septic tanks	73	4 0

(*b*) Working and Sludging of Tanks.

77. For the working and sludging of the tanks we estimate that the services of three men would be required in the case of the two chemical precipitation processes and in that of quiescent settlement, and of two men in the case of the continuous flow settlement process and the septic tank process.

Taking labourers' time at 21s. a week, and including one-third of the manager's time, at the salary of £130 per annum, we obtain the following figures :—

Preliminary Process.	Labour and Supervision in connection with Tanks.	
	Per annum.	Per million gallons of sewage (dry weather flow).
	£	s. d.
Quiescent settlement with chemicals	208	11 5
Continuous flow settlement with chemicals	208	11 5
Quiescent settlement without chemicals	208	11 5
Continuous flow settlement without chemicals	152	8 4
Septic tanks	152	8 4

Loan Charges.

78. Taking the price of land at £100 per acre, and assuming that the loan is raised at 3½ per cent interest per annum and is repayable in equal annual instalments in thirty years, the annual loan charges in respect of the initial cost of tanks and of the land on

which the tanks are constructed and in which the sludge is buried would be as shown in the following table:—

Preliminary Process.	Loan Charges. Per annum.			Loan Charges. Per million gallons of sewage (dry weather flow).		
	£	s.	d.	£	s.	d.
Quiescent settlement with chemicals	374	5	9	1	0	6
Continuous flow settlement with chemicals	251	4	11	0	13	9
Quiescent settlement without chemicals	364	7	9	0	19	11
Continuous flow settlement without chemicals	314	12	8	0	17	3
Septic tanks	404	4	11	1	2	2

Total Cost of the Preliminary Processes.

79. Arranged in the order of their total annual cost, including repayment of principal and interest on loans, the five processes are as follows :—

	£	s.	d.
Continuous flow settlement without chemicals	564	12	8
Septic tanks (open tanks)	629	4	11
Quiescent settlement without chemicals	724	7	9
Continuous flow settlement with chemicals	1,134	19	11
Quiescent settlement with chemicals	1,258	0	9

The details are:—

Per Annum.

Preliminary Process.	Chemicals. £	s.	d.	Labour and Supervision. £	Loan Charges. £	s.	d.	Total. £	s.	d.
Quiescent settlement with chemicals.	523	15	0	360	374	5	9	1,258	0	9
Continuous flow settlement with chemicals.	523	15	0	360	251	4	11	1,134	19	11
Quiescent settlement without chemicals.	—			360	364	7	9	724	7	9
Continuous flow settlement without chemicals.	—			250	314	12	8	564	12	8
Septic tanks	—			225	404	4	11	629	4	11

Per Million Gallons of Sewage (dry weather flow).

Preliminary Process.	Chemicals. £	s.	d.	Labour and Supervision. s.	d.	Loan Charges. £	s.	d.	Total £	s.	d.
Quiescent settlement with chemicals.	1	8	8	19	9	1	0	6	3	8	11
Continuous flow settlement with chemicals.	1	8	8	19	9	0	13	9	3	2	2
Quiescent settlement without chemicals.	—			19	9	0	19	11	1	19	8
Continuous flow settlement without chemicals.	—			13	8	0	17	3	1	10	11
Septic tanks	—			12	4	1	2	2	1	14	6

In so far, therefore, as the preliminary tank process by itself is concerned, it will be seen that, *on the basis of the above calculations*, settlement either by continuous flow or in open septic tanks is only half as costly as chemical precipitation. It will be noted that quiescent settlement, as compared with continuous flow settlement, does not add greatly to the total annual cost, while it gives distinctly better results.

Filtration of Tank Liquor.

80. In most cases sewage must not only be settled, but must also be filtered, and it is therefore desirable to consider the cost of the preliminary process *in conjunction with* the final or filtration process.

"Strength" of the Liquors Produced.

From the data obtained at Dorking, Leeds, and Huddersfield, where chemical precipitation (continuous flow), settlement without chemicals (continuous flow) and septic tank treatment, have been compared on the same sewage, and from our general experience, we estimate the strengths* of the five tank liquors which would be produced from our hypothetical domestic sewage, and the approximate amount of suspended matter which would be contained in each, as follows :—

Preliminary Process.	* Strength of Sewage.	* Strength of Tank Liquor	Average Amount of Suspended Matter in Tank Liquor.
Quiescent settlement with chemicals	100	50	1 to 4 parts
Continuous flow settlement with chemicals	100	60	3 „ 6 „
Quiescent settlement without chemicals	100	70	5 „ 8 „
Continuous flow settlement without chemicals	100	80	10 „ 15 „
Septic tanks	100	80	10 „ 15 „

Final Purification of the Tank Liquors.

81. On the grounds set out in a later section of this report, we consider that the amount of tank liquor which can be treated on a filter depends upon the strength of the liquor and the amount of suspended matter which it contains, and further, that some filters are more suitable for the filtration of certain kinds of tank liquor than others. For the purpose of our present comparison we have selected percolating filters composed of rather coarse material, say, 1 to 3 inches in diameter. The rate of filtration at which such filters could be used with each of the five preliminary processes, so as to yield satisfactory effluents, is shown in the following table :—

Preliminary Process.	Strength of Tank Liquor.	Amount of Suspended Matter in Tank Liquor (parts per 100,000).	Rate of Filtration per cube yard per day (dry weather flow).	Cubic Content of Filtering Material required to treat 1 million gallons per day (dry weather flow).
			gallons.	cubic yards.
Quiescent settlement with chemicals	50	1 to 4	175	5,714
Continuous flow settlement with chemicals	60	3 „ 6	150	6,666
Quiescent settlement without chemicals	70	5 „ 8	100–125	8,928
Continuous flow settlement without chemicals	80	10 „ 15	75–100	11,494
Septic tanks	80	10 „ 15	75–100	11,494

* The strength is calculated on the basis of the formula suggested by Dr. McGowan, *see* page 16.

The total annual cost of five sets of percolating filters of coarse material, we have calculated to be as follows* :—

Preliminary Process.	Total Cost of Filtration, including loan charges.					
	Per annum.			Per million gallons (dry weather flow).		
	£	s.	d.	£	s.	d.
Quiescent settlement with chemicals	572	19	7	1	11	5
Continuous flow settlement with chemicals	661	11	3	1	16	3
Quiescent settlement without chemicals	766	9	2	2	1	11
Continuous flow settlement without chemicals	960	8	5	2	12	8
Septic tanks	960	8	5	2	12	8

The total cost of the complete treatment in each case (loan charges included) would therefore be as follows :—

Per Annum.

Preliminary Process.	Total Cost of Preliminary Treatment.			Total Cost of Filtration Process.			Total Cost of complete Treatment.		
	£	s.	d.	£	s.	d.	£	s.	d.
Quiescent settlement with chemicals	1,258	0	9	572	19	7	1,831	0	4
Continuous flow settlement with chemicals	1,134	19	11	661	11	3	1,796	11	2
Quiescent settlement without chemicals	724	7	9	766	9	2	1,490	16	11
Continuous flow settlement without chemicals	564	12	8	960	8	5	1,525	1	1
Septic tanks	629	4	11	960	8	5	1,589	13	4

Per Million Gallons (dry weather flow.)

Preliminary Process.	Total Cost of Preliminary Treatment.			Total Cost of Filtration Process.			Total Cost of complete Treatment.		
	£	s.	d.	£	s.	d.	£	s.	d.
Quiescent settlement with chemicals	3	8	11	1	11	5	5	0	4
Continuous flow settlement with chemicals	3	2	2	1	16	3	4	18	5
Quiescent settlement without chemicals	1	19	8	2	1	11	4	1	7
Continuous flow settlement without chemicals	1	10	11	2	12	8	4	3	7
Septic tanks	1	14	6	2	12	8	4	7	2

* *See* page 105.

Arranged in the order of cost the five complete processes are as follows :—

——	Total Cost per Annum.			Total Cost per Million Gallons. (dry weather flow).		
	£	s.	d.	£	s.	d.
Quiescent settlement without chemicals	1,490	16	11	4	1	7
Continuous flow settlement without chemicals	1,525	1	1	4	3	7
Septic tanks (open)	1,589	13	4	4	7	2
Continuous flow settlement with chemicals	1,796	11	2	4	18	5
Quiescent settlement with chemicals	1,831	0	4	5	0	4

Conclusions.

82. The above figures have been arrived at by making a number of assumptions, but they are based upon a large mass of evidence and experience.

We have not had an opportunity of making comparative observations, as regards all the processes, at one place.

The figures show that there is little difference as regards annual cost between the processes of quiescent and continuous flow settlement of sewage and septic tank settlement, when these are adopted in conjunction with percolation through filters of coarse material, the maximum difference being only 6 per cent. On the other hand, the two processes of chemical precipitation are from 20 to 25 per cent. more costly than the cheapest of the simple settlement processes. As regards this point, however, it must be remarked that sewage which has undergone chemical precipitation contains less suspended and colloidal matter than sewage which has been passed through a septic tank, or than sewage which has been settled without chemicals, and therefore it can be treated on a filter of finer material, and in that case a smaller number of cubic yards of material than we have allowed for in this comparison would suffice for its purification.

In this connection, it may also be pointed out that, where sewage is freed, as far as possible, from suspended matter, a large extra quantity may, in times of storms, be passed through coarse percolating filters, without injury to the filters.*

In the absence of special circumstances favouring a particular plan, it would appear that there is very little difference in annual cost between the various methods of tank treatment followed by filtration through percolating filters, assuming that the kind of filter adopted in each case is that which is best adapted to the particular tank treatment provided.

Some Observations on the Choice of Tank Treatment.

83. The form of preliminary treatment which should be adopted at a given place should depend *mainly* upon the means at hand for the disposal of sludge, and upon the class of filter to be used in the subsequent filtration of the tank liquor. If fine filters are to be used for the oxidation of the tank liquor, the tank treatment should generally be such as will eliminate a large proportion of the suspended and colloidal matter.

We shall make some further observations on this aspect of the question in the section dealing with filters. With a tank liquor of given strength, and containing a given quantity of suspended and colloidal matter, it is of little consequence, as regards the subsequent filtration, by what method of preliminary treatment this liquor has been obtained.†

* *See* Leeds Report 1905, pp. 114, 115.

† From the result of the experiments at present in progress at Dorking, the above statement may have to be somewhat modified. The neutralisation of the sulphuretted hydrogen of the septic liquor and the slightly increased alkalinity given by the lime appear to allow of a very considerable increase in the volume which may be filtered per cube yard, greater than would follow from the mere reduction in suspended solids effected by this precipitation.

The nature of the sewage to be treated should, however, be considered in selecting the tank treatment to be adopted.

Domestic sewages may be divided into three classes, viz. :—

(1) Domestic sewages which are very strong;

(2) Domestic sewages of about average strength; and

(3) Weak domestic sewages.

Domestic Sewages which are very Strong.

84. Very strong sewages, derived from towns where the water-closet system is in vogue, contain more suspended and colloidal matter than weak sewages. Our analyses, so far as they go, have shown that the actual proportion of colloidal to suspended matter in sewage is not great; but since the amount of colloidal matter is frequently somewhat larger in a septic tank liquor than in its corresponding sewage, the proportion of colloidal to suspended matter in a strong septic tank liquor may be considerable. Such a liquor would exercise a greater clogging effect upon a filter of fine or medium-sized material than its figure for "suspended solids" would lead one to expect. Moreover, the septic liquor and sludge produced from such a sewage would almost certainly give rise to considerable smell, and if the sewage contained much brewery or tannery waste the smell would be still more pronounced.

Where sewage has to be pumped its character may be abnormal. It may remain for a considerable time in the main sewer or sewers, and become "septic" in character before it reaches the outfall. Moreover, in such cases, surface water is often rigorously excluded so as to diminish the cost of pumping, and the strength of the sewage is thus increased.

In the majority of cases we think it would probably be better to adopt chemical precipitation rather than septic tanks as the preliminary process for very strong water-closet domestic sewages, and especially would this be the case if the sewage contained an appreciable quantity of brewery or tannery waste.* Precipitation with chemicals has the effect of throwing down, as sludge, a considerable proportion of the colloidal matter present, and some precipitants have the power of retarding for a short time the putrefaction of the sludge, so that precipitation sludge, if removed from the tanks at short intervals of time, can usually be disposed of with less danger of nuisance than septic tank sludge. It may also be remarked that the addition of lime to a putrid domestic sewage is followed by a great diminution of the smell.

Moreover, chemically precipitated sludge is, volume for volume, usually much less costly to press than septic tank sludge, especially if it is derived from a strong domestic sewage of the kind indicated above; indeed the quantity of lime which has to be added to some septic tank sludges makes the cost of pressing almost prohibitive.

Simple sedimentation of a sewage of this class would also be less advantageous than chemical precipitation. Little colloidal matter would be removed from the sewage, and there would be more danger of nuisance from smell during the sludging of the tanks and the sludge disposal operations.

85. As regards very strong domestic sewages consisting for the most part of slop-water there is, apart from the question of cost, little to choose between the various methods of settlement. The bulk of the suspended matter in such a sewage settles fairly rapidly, leaving a soapy liquid containing a considerable quantity of greasy suspended matter. Such sewages are, however, usually to be found at small places where labour for frequent sludging would not be available, and in these circumstances septic tanks would usually be more economical than sedimentation or chemical precipitation tanks, and they would produce a tank liquor which would be suitable for filtration through coarse filters.

* The success which has attended the treatment of the Dorking septic tank liquor with a small quantity of lime makes it appear possible that in some cases the combination of the two processes—*i.e.*, septic tank treatment followed by lime precipitation—would be preferable to precipitation alone (*c.f.* paragraph 56 and note on p. 43).

We have had opportunities for observing the treatment of sewages of this kind by various methods of settlement, including septic tanks (Hemsworth), settling tanks used on the continuous flow plan (Clifton, Lancashire), and chemical precipitation followed by quiescent settlement (Withnell). The two examples of chemical precipitation followed by continuous flow settlement which we have had under observation—Calverley and Normanton (Yorkshire)—did not give very good results as regards settlement, the suspended matter in the tank liquor being above 12 parts per 100,000 in both cases. The reasons for this were that the sewage varied greatly in strength throughout the day, and the proper addition of the precipitant was a matter of much difficulty; and, as is common at some places, the tanks were allowed to run too long without cleaning.

Domestic Sewages of about Average Strength.

86. For domestic sewages of about average strength, whether of the slop-water or water-closet type, the choice of the preliminary process should depend upon local circumstances and upon the kind of filters to be adopted. With such sewages equally good final results may be obtained either from septic, sedimentation, or chemical precipitation tanks, followed by artificial filters, though the size of the material to be used in the filter should depend, to some extent, on which tank treatment was adopted. The least amount of sludge is produced by the septic tank and the greatest amount by the chemical precipitation tank, but a larger area of filter is required for the treatment of the septic tank liquor than for the treatment of the precipitation tank liquor. Approximately the same filter area is required for the filtration of sewage from sedimentation tanks used with a continuous flow as for septic tank liquor. If quiescent sedimentation is adopted, a smaller area of filter will suffice. Excepting at very small places, where the labour costs for the constant sludging of the tanks would be disproportionately high, or in cases where pumping would be required, quiescent sedimentation gives considerably better results as regards suspended matter than continuous flow sedimentation, at practically the same cost.

Weak Domestic Sewage.

87. The last 4 or 5 parts of suspended matter are extremely difficult to throw down as sludge, and in the case of weak sewages the difference between the various tank treatments, as regards suspended matter in the resulting liquors, is not nearly so great as it is in the case of strong sewage.

For this reason, the advantage as regards amount of sludge produced and saving in cost of chemicals which the preliminary processes of septic tank treatment and continuous flow sedimentation have over chemical precipitation, is of greater importance with weak than with strong sewages. The septic tank process would, we think, generally be most economical for a weak sewage, if land were available for the burial of the sludge. The sludge produced would not have a very offensive smell, and might indeed in some cases be comparatively free from smell. If, however, no land were available for the burial of the sludge, the extra cost of pressing septic tank sludge would materially diminish the advantage of septic tank treatment.

Summary for Domestic Sewage.

88. Speaking generally, we should say that chemical precipitation is more suitable for strong sewages or sewages likely to give rise to nuisance, while septic tank treatment or sedimentation would usually hold the advantage in the case of weak sewage. For sewage of about average strength there is probably little difference between the three processes, and the selection of the process would depend chiefly upon the facilities for sludge disposal, the position of the works as regards houses, and the kind of filters to be adopted.

It must be remembered, however, that there are other considerations which may affect the question. A particular sewage, for example, may be liable to great variations in strength and character, and the equalising effect which the septic tank has on such a sewage is a point of considerable importance.

Moreover, it is by no means to be thought that finality has been reached in the preliminary treatment of sewage. New combinations of tanks or of processes may lead to much improvement; a cheap deodorant for sludge may be found, etc. In this connection, we may refer to the results of our experiments at Dorking upon the treatment of sewage by septic tanks, followed by precipitation with lime, which are mentioned on p. 29.

Sewage from large Cities.

89. The presence of trade waste in large or preponderating quantity has an important bearing upon the preliminary treatment of the sewage from a large city. Where the sewage contained much brewery waste, lime would probably have to be added for the purpose of neutralisation, as at Burton-on-Trent; where it was strongly alkaline, or very greasy, acid might have to be used as the precipitant, as at Bradford; where it contained much tarry matter or matter which had an inhibitory effect upon the activity of purifying organisms, septic tanks might be preferable, by reason of the longer stay which they give to the sewage. Manchester may be cited as an example of this last case. For these reasons it is impossible to make any but the broadest generalisations with regard to the preliminary treatment of the sewage from large cities, whether it be weak or strong.

Where very large areas of filters have to be put down, it is of considerable importance to protect them against clogging, and we think that it will usually be found best in the case of a large city to adopt effective means for the removal of most of the suspended matter before filtration. In the majority of cases this would involve the adoption of chemical precipitation, though not necessarily in all, for Mr. Watson, of Birmingham, has shown that a well clarified tank liquor can be obtained by interposing Dortmund tanks between the septic tanks and the filters. The Birmingham septic liquor contains on the average about 20 parts of suspended matter before entering the Dortmund tanks, but only about 6 parts when it leaves them. This liquor from the Dortmund tanks has now been treated for some years on percolating filters without serious clogging. It must be pointed out as regards Birmingham, however, that at that place there is a very large area of land available for the disposal of sludge. If it were not for this, sludge pressing might have been necessary, and having regard to the difficulty of pressing septic tank sludge, it might have been desirable to adopt chemical precipitation.

PART II.—PURIFICATION OF SEWAGE BY ARTIFICIAL FILTERS.

INTRODUCTORY REMARKS.

90. Sewage filters may be divided into two broad classes:—contact beds and percolating filters.

Contact beds are tanks filled with some filtering medium. In this type of filter, the sewage is held up before it is discharged. The bed, after it is emptied, is allowed to remain empty for some time before receiving the next filling. The length of time during which the sewage is allowed to stand in the bed is spoken of as the period of contact.

In percolating filters the sewage is not held up, but is allowed to percolate through the filter.

There can be no doubt that the organic matter in solution in sewage can be oxidised by either type of filter, provided the filter is properly constructed and properly worked, but the question of the relative merits of the two types is one of some difficulty, as very few strictly comparative experiments on a large scale have been made.

SOME OBSERVATIONS AS TO THE EXTENT TO WHICH THE SUSPENDED SOLIDS SHOULD BE REMOVED FROM SEWAGE BEFORE IT IS FILTERED.

91. No rule can be laid down as to the extent to which the suspended solids should be removed from sewage before it is filtered, but, speaking generally, if it is proposed to use filters of fine material, we think it will be found most economical to adopt some form of tank treatment which will yield a tank liquor fairly free from suspended solids; whereas, if coarse filtering material is to be used, this is not so essential.

If much suspended matter is put on fine filters, they are likely to choke very rapidly unless the rate of filtration is very slow.

Under the heading "Some observations on the choice of a method of sewage treatment," page 202, a number of points are mentioned which should be taken into account in determining what method of treatment should be adopted in any particular place, and in this section we only propose to give the results of our general experience as to the amounts of suspended matter, which, having due regard to the life of the filter and to the quality of effluent, may be allowed with certain kinds of filters, worked at certain rates.

The figures relate to domestic sewage, or sewage containing only small amounts of trade refuse, of average strength.

The rates of filtration which we give could generally be doubled in wet weather. Thus, assuming it was desired to provide enough filtering material to filter in storm times up to three times the dry weather flow of sewage, the amount of material required would be 50 per cent. more than the amount which would be required for the dry weather flow, calculated on our figures.

I.—Contact Beds.

Coarse Material (3 ins. diameter and upwards).

92. Grit-settled sewage containing 20 to 30 parts of suspended matter could be treated at the rate of 1 to 1½ fillings per day (about 30 to 40 gallons per cube yard * per day for double contact) upon material of this size in contact beds; if the sewage contained 30 to 50 parts of suspended matter per 100,000, the rate of treatment should not exceed 1 filling per day (about 30 gallons per cube yard per day for double contact). In both cases provision would have to be made for thoroughly washing the material in the beds about once every 18 months or 2 years. Secondary beds of medium-sized material, used subsequently, would probably have to be washed every 4 or 6 years.

Medium-sized Material (½ in. to 1 in. diameter).

93. Tank liquors containing 10 to 15 parts of suspended matter per 100,000 could be treated upon material of this size at the rate of about 2 fillings per day (50 gallons per cube yard * of filtering material per day for double contact, or 100 gallons per cube yard for single contact), but the material would have to be thoroughly washed or renewed every 3 to 5 years. If the tank liquor contained from 4 to 7 parts of suspended matter per 100,000, the rate of treatment might be 3 (about 80 gallons per cube yard * per day for double contact, or 160 gallons per cube yard for single contact) or, at times, 4 fillings per day, and the beds would probably have to be washed every 4 or 5 years. In both these cases the material in the secondary beds would probably not require to be washed for 7 or 8 years.

* See footnote on next page.

If the liquor contained from 1 to 4 parts of suspended matter per 100,000 it could probably be treated at a rate of 4 to 6 † fillings per 24 hours (about 100 to 160 gallons per cube yard * per day, for double contact), and the material might not need washing for 6 to 8 years, or possibly even longer. Secondary beds, in this case, would probably last for 12 or 15 years.

Fine Material (¼ in. diameter).

94. It would be inadvisable, we think, to attempt to treat tank liquors containing more than 4 or 5 parts of suspended matter per 100,000, on material of this size. A good tank liquor, containing from 1 to 4 parts of suspended matter could, probably, be well filtered at the rate of from 4 to 6 * fillings per day (about 100 to 160 gallons per cube yard † per day for double contact or 200 to 320 gallons per cube yard for single contact), and the material would, probably, not have to be washed for 6 or 8 years. The upper part of the material in secondary beds would, probably, have to be washed every 12 or 15 years.

II.—Percolating Filters.

Coarse Material (3 in. diameter and upwards).

95. Grit-settled and screened sewage could be treated on a percolating filter composed of material of this size even if it contained as much as 30 parts of suspended matter per 100,000, provided such suspended matter was not largely made up of fibrous material, hops, etc. If the sewage was of average strength, it could, probably, be filtered at a rate of about 50 gallons per cube yard per day. The upper part of the material would, we think, have to be removed and replaced about every 2 years, and the lower part flushed through with water or clarified sewage.

Tank liquors containing, say, 10 to 20 parts of suspended matter per 100,000, might be treated upon this material for long periods of time (say, 10 to 15 years) with occasional renewal of the top foot of material. If the tank liquor was of about average strength, it could be filtered at a rate of about 100 gallons per cube yard per day.

A tank liquor of about average strength, containing from 4 to 7 parts of suspended matter per 100,000, could similarly be treated on coarse material, but in this case the rate of filtration might be about 100 to 150 gallons per cube yard per day.

A tank liquor, containing from 1 to 4 parts of suspended matter per 100,000, could be filtered for even longer periods of time on coarse material, and, if it were of about average strength, at a rate of 150 or possibly 200 gallons per cube yard per day.

In all these cases the filtration might occasionally be affected by fungoid growths on the surfaces of the filters. Provision would generally have to be made in the first three cases, and possibly in the last also, for the settlement or the straining, through fine material, of the filter effluent, in order to reduce the suspended matter contained in it.

Medium-sized Material (½ in. to 1 in. diameter).

96. Grit-settled and thoroughly screened sewage could generally be treated upon material of this size, even though it contained as much as 30 parts of suspended matter per 100,000. The rate of filtration, however, should not exceed 25 gallons per cube yard per day, and even in that case the upper part of the material would probably require to be washed every 2 or 3 years. The plan would, we think, not be economical, except at very small places.

* There are good grounds for putting the average water capacity of a primary contact bed during its working life at about 33 per cent. of its original empty tank capacity. These estimates are consequently based upon that assumption. We estimate that the average capacity of a secondary bed during the lifetime of its complementary primary bed, is about 40 per cent. of its original empty tank capacity. If this is taken into account, *i.e.*, if the secondary beds are made proportionately smaller than the primary beds, the rates of filtration per cube yard per day will be rather greater in each of the cases given above.

† With large beds such a high rate of working would, probably, be only practicable for short periods of time.

Tank liquors containing from 10 to 15 parts of suspended matter per 100,000 could generally be treated on this material at a rate of about 50 gallons per cube yard per day, if the upper part of the material were washed or renewed once in 3 or 4 years, and provided also that the bed were well rested immediately any signs of ponding occurred.

A tank liquor containing from 4 to 7 parts of suspended matter per 100,000 could generally be filtered at a rate of 75 to 100 gallons per cube yard per day. The upper part of the material would probably require washing or renewal once in 3 to 5 years.

A very good tank liquor containing from 1 to 4 parts of suspended matter could generally be filtered at a rate of 150 to 200 gallons per cube yard per day, provided the filter were carefully rested when necessary, and also that the liquor was not of a kind liable to give rise to fungoid growths. The material in this case would probably last without washing for 5 or 6 years, or possibly even longer, though it might be advisable to wash or renew the uppermost few inches every 1 or 2 years.

In the first three mentioned cases, and possibly in the last also, provision would usually have to be made for the reduction of the suspended matter in the filter effluent.

Fine Material (¼ *in. diameter*).

97. It would be inadvisable, we think, to attempt to filter tank liquors containing more than 6 or 7 parts of suspended matter per 100,000 on material as fine as this. Crude sewage, for instance, would clog the surface of such material in a very short time, unless the rate of filtration were exceedingly slow, and even then the surface of the material would have to be constantly scraped and cleaned.

Tank liquors containing from 4 to 7 parts of suspended matter per 100,000 could generally be filtered at a rate of 75 to 100 gallons per cube yard per day. The upper part of the material would require washing or renewal about once in 4 or 5 years.

A tank liquor containing from 1 to 4 parts of suspended matter per 100,000 could probably be filtered at a rate of 150 to 200 gallons per cube yard per day, and the material in the upper part of the filter would probably require washing once in 4 or 5 years. The higher rate could only be maintained, if the filters were shallow.

Very fine Material (⅛ *in. diameter and smaller*).

98. Where material, such as sand, is used for a filter, or where the filter is protected with a surface layer of sand, only very well clarified tank liquors can be treated, unless the rate of filtration is very slow and the surfaces of the beds are scraped or washed at short intervals. Such filters must necessarily be used intermittently.

For tank liquors containing from 4 to 7 parts of suspended matter per 100,000, the rate of filtration should probably not exceed 50 gallons per cube yard per day, and the surfaces of the filters would have to be scraped after every one or two applications of the liquor. If the fine material alone were relied upon for the distribution of the liquid, the rate of filtration might possibly have to be slower. If very fine-grained filters were arranged in the shallow form and were washed by upward flow every one or two weeks, it would be possible to treat a very good tank liquor from a sewage of about average strength, containing, say, 1 to 4 parts of suspended matter per 100,000, at rates of from 200 to 300 gallons per cube yard per 24 hours. The liquor would have to be delivered intermittently, and the distribution must of course be efficient. At Chorley, where such a tank liquor is delivered on to filters of this kind, the rate of filtration is upwards of 350 gallons per cube yard per day. Here, the tank liquor is delivered in large flushes which cover the whole surface of each bed to a depth of 2 or 3 inches, and the surface of the beds is frequently washed.

CONTACT BEDS.

99. Our knowledge of the action of a contact bed is very incomplete, and little is known as to the manner in which the organic substances of sewage are broken down during the first stages of fermentation into carbon dioxide, ammonia, etc. The purifying agents seem to be not only bacteria, but also worms, larvæ, insects, etc., and we can offer no opinion as to the respective amount of work done by each set of agents. It probably differs to some extent according to the nature of the sewage. It has been observed that at some places large numbers of worms are present, while at others there are comparatively few. Little is known of the kind of bacteria essential for purification, or as to their mode of action, and we are not able to state whether they act chiefly during the period of contact or during the period of rest, or aeration, after the filter is emptied. There are, however, grounds for thinking that the resting period is the more important phase of the cycle.

The generally accepted theory as regards nitrogenous matter seems to be that the ammonia is extracted from the liquid during the period of contact, and oxidized during the period of rest, and that the resulting nitrate and nitrite are diffused through the liquid of a subsequent filling. All the ammoniacal nitrogen, however, does not appear in the effluent in the oxidized state, for there is always loss of nitrogen, as nitrogen gas, during the process.

The withdrawal of suspended and colloidal matter from the sewage during its passage through the bed appears not to be a simple mechanical effect of the material, for a matured contact bed, not clogged, will withdraw more suspended matter from the sewage than another bed similar in all other respects, but not matured. As regards the action which takes place in a contact bed, we may also refer to the evidence of Mr. Dibdin, Dr. Rideal, Mr. Harrison, Mr. Valentine and Dr. Fowler.

Dibdin, 2176, 3902–5.
Rideal, 4133, 4207–8.
Harrison, 22(
Valentine, 22
Fowler, 2281

Construction of Contact Beds.

100. In some cases contact beds have been made by simple excavation, but our experience and the evidence which we have received show that in the majority of cases it is desirable that the beds should be constructed of building materials.

When contact beds are constructed by simple excavation in clay soil, there is risk of the clay sooner or later, according to the character of the stratum, working up into the filtering material. Moreover, the lines of underdrains are apt to become distorted, as the result of unequal settlement.

Wilkinson, 24
Wike, 23588

At Heywood an experimental bed was constructed, without concrete, in clay soil, and it was found that the clay worked up into the bed and formed an impervious mass round the drain pipes.

Again, there is danger of leakage unless the soil is of a very dense nature and the embankments are of considerable width. This leakage may occur as a result of unequal settlement, or through rats or moles burrowing into the embankment, or through the cracking of the clay during periods of rest or frost. The result of leakage may be detrimental to the working of the bed. Two instances which have come under our own observation may be mentioned.

At Halton it was found necessary to fill two of the primary contact beds simultaneously, as the liquid percolated from one bed to the other through the intermediate embankment.

At Oswestry, where double contact beds were constructed in fairly stiff clay soil, some of the retaining banks became sodden with liquid after three or four years' work and sank considerably in consequence.

Even in the most impervious kind of soil the outlet chambers of contact beds must be constructed of building materials, and, unless this work is most carefully carried out, there is danger of leakage at the juncture of the chamber and the embankment. It may also be remarked that the embankments required, where no building materials are used, take up more space than properly built walls.

On the other hand, where the site for the works consists of a dense clay, experience shows that the construction of contact beds by simple excavation may be satisfactory.

As examples, we may refer to the beds at Burnley and Oldham.

At Burnley twenty-four acres of double contact beds have been constructed by simple excavation in loam and heavy clay soil. The oldest of the Burnley beds was brought into use about ten years ago.

At Oldham, where the soil is chiefly clay, with pockets of sand in places, five acres of single contact beds have been constructed by simple excavation, the sides being puddled where necessary and boarded up with 3-inch planking.

In both these cases the construction has been fairly satisfactory.

101. The construction of the bottom of a contact bed should be such as to allow of the treated liquid being drawn off quickly, but quietly, in order to give the material the longest possible rest and aeration.

The liquid which, at the commencement of the filling, finds its way into the drains of a contact bed is not purified to the same degree as the bulk of the liquid throughout the filtering material, and, for this reason, the drains of a contact bed should not be larger than is necessary to allow of the thorough draining of the bed.*

It has been suggested that this difficulty of unequal purification might, to some extent, be overcome by constructing the drains so that they would remain full of filter effluent after the bed had been run off. We are not aware that this course has been actually tried, but if it were adopted, great care would have to be taken to construct the drains below the level of the material, and to place the outlet valve in such a position as to preclude the possibility of effluent standing amongst the lower layers of the material during the resting period. Whether the aeration of the bed, during the "rest," would be affected we are unable to say. In any case it would be inadvisable to attempt this plan of draining where the bottom was not constructed of concrete or some such material.

In order that the withdrawal of the liquid may be gentle, as well as rapid, it is desirable to provide several drains, especially in a large bed.

102. Two points of detail may be mentioned here which are of some importance :—

The outlet valve of a contact bed should be fixed in such a position that a proper sample of the filter effluent can be collected from it. In a number of cases we have found it very difficult to draw proper samples of effluent from contact beds, owing to the outlet valves being placed low down in the channel along which effluents from other beds were flowing, and in these cases it has not been easy to ascertain the efficiency of the individual beds.

The feed channels to the secondary beds should be constructed so as to provide reasonable facilities for measuring the capacity of the beds. These beds are frequently so constructed that accurate measurements of capacity cannot be made.

Depth of Contact Beds.

103. The evidence shows that, within ordinary limits, the depth of a contact bed makes, practically, no difference to its efficiency per cube yard.

At Leeds, experiments were made with three contact beds of different depths, filled with similar material, and treating the same tank liquor. These beds were, respectively, 5 feet deep, 4 feet deep, and 3 feet 6 inches deep.

The bed 5 feet in depth received septic tank liquor at the rate of two fillings per day, with one week's rest in every four. During the period from July, 1901, to March, 1905, the effluent showed, according to Mr. Harrison's analyses, an average reduction of 78·6 per cent. in oxygen absorbed from permanganate in four hours.

* *Note.*—The actual size of the drains would depend to some extent upon the size of the material.

The bed 4 feet deep received septic tank liquor at the rate of one filling per 24 hours, from August 17th, 1901, to January 11th, 1905. The effluent showed an average reduction in oxygen absorbed from permanganate in four hours of 80·3 per cent.

The bed 3 feet 6 inches deep received septic tank liquor for fourteen months, at a rate of three fillings per day, and gave an average reduction in oxygen absorbed from permanganate in four hours of 74 per cent.

Taking into account the differences in working, there was no great difference in the results obtained in this experiment, and so far as we could judge from a careful comparison of the results at the time the experiments were made, none which could be ascribed to the depth of the filters.

The experience of Dr. Clowes in connection with some experiments which he carried out at the London sewage works was in agreement with that of the Leeds experiments.

For further details on this question reference may be made to the evidence of Mr. Harrison, 22005; Mr. Valentine, 22450; Dr. Fowler, 22792; Mr. Wyke, 23599; Mr. Wilkinson, 24283; Mr. Campbell, 21652 and 21883; and Dr. J. B. Wilkinson, 22643.

104. From our own experience of contact beds, we think that it would be generally inadvisable to construct them of a greater depth than 6 feet or of a less depth than 2 feet 6 inches.

In order that a contact bed may drain properly, it is necessary to have a few inches of large material on the floor of the bed, and this material, with the drains themselves, would occupy about 6 inches of depth. The sewage which remains among this coarse material, or in the drain spaces, during the time when the bed is full, is not so well purified as the liquor which is standing amongst the finer material in the upper part of the bed, and it is found that the first flush from a contact bed, which comes from the lowest part of the bed, is usually considerably worse than the main bulk of the effluent. As a general rule, we doubt whether it would be wise to allow this less efficient portion of the bed to form more than one-fifth of the whole depth, and for this reason we suggest that the minimum depth should usually be not less than 2 feet 6 inches.

As regards the maximum depth of contact beds we may observe :—

(*a*) That an increase in depth puts a greater weight upon the filtering material in the lower part of the bed, and may cause disintegration.

(*b*) That the difficulty of digging and handling the material, when washing is necessary, is greater with deep than with shallow beds, and that the operation would require a greater amount of labour and would result in more breaking down of the material during the process.

105. Our experience of contact beds ranges from the deepest of the Leeds beds, 6 feet deep, to the shallow contact beds at Oldham, 1 foot 6 inches deep, the depths of the contact beds at the various places which we have had under observation being :—

Leeds	From 6 feet to 3 feet.
Exeter (St. Leonards)	5 feet.
Hendon	5 feet (about).
Slaithwaite	5 feet.
Withnell	5 feet and 3 feet 6 inches.
Oswestry	4 feet 6 inches.
Exeter (Main works)	4 feet 6 inches.
Maidstone	4 feet 4 inches and 3 feet 3 inches.
Halton	4 feet 3 inches and 3 feet 3 inches.
Hartley Wintney	4 feet.
Andover	4 feet.

Hampton	4 feet.
Newton-le-Willows	3 feet 6 inches.
Calverley	3 feet.
Guildford	2 feet 6 inches.
Oldham	1 foot 6 inches.

Filling and Emptying of Contact Beds.

106. The evidence shows that two hours' contact and four hours' rest have generally been found to give the best results in practical working, where the beds are filled three times a day, but no rule can be laid down which is of universal application.

As regards this question Dr. Fowler stated in reference to his Manchester experience that the periods depend almost "entirely on the age of the bed and the dilution of the "sewage. In the initial stages of working, long contacts (*e.g.*, twenty-four hours) have been "found advantageous, their effect being to facilitate the formation of a slimy layer of col- "loidal matter on the medium, in which the real biological action begins. As this layer "increases, the 'absorptive' effect increases also, and less time of contact is required. More- "over, a greater quantity of water is held up in a bed, and the quantity of 'draining' in- "creases, till with a bed in long use a very short contact, say, a quarter of an hour, is all "that is required. With increase in dilution of the tank effluent, due, *e.g.*, to storm water, "the period of contact may be reduced to a minimum. In general, after the bed is once "'mature,' the period of rest is more important than the period of contact, and the total "time occupied in twenty-four hours in filling, standing full, and emptying should not "exceed the total of the period of rest. Thus, with frequent fillings, the time of contact "should be shortened. If the bed takes long to fill, the extra time in filling should be taken "from the time of contact. The above also applies to secondary beds, it being understood "that, as they deal with an effluent containing less impurity, they can be worked more "rapidly than primary beds." Fowler, 22798

At Calverley the period occupied by filling and standing full varied from six to twenty-four hours, the beds being filled, on an average, less than once a day. A good percentage purification on a strong precipitation liquor was obtained by single contact, but the liquor was too strong to allow of single contact producing a satisfactory effluent. The beds retained their capacity well. A long contact apparently helps to break down the suspended solids and to allow of their passing out of the beds in very considerable quantity.

107. Unless the circumstances are exceptional, we think that, in designing a contact bed scheme, a contact of two hours' duration should be provided for, leaving subsequent experience to show whether this could not be shortened to some extent. The period of contact should be fairly regular, as sudden variations may, we think, have a disturbing effect upon the agents of purification. We have noticed, for instance, in beds generally giving two hours' contact, that if the sewage is occasionally held up for a much longer time, say, five or six hours, great numbers of worms are driven to the surface.

It is also desirable that the fillings should be as far apart from one another as practicable, (*e.g.*, to give three fillings in three cycles of eight hours each, rather than three fillings in twelve hours followed by a twelve hours' rest), so that the maximum period for drainage and aeration between the fillings may be obtained.

108. The operations of filling and emptying should be carried out as rapidly as possible, but care must be taken to avoid disturbance of the filtering material, as this may cause disintegration.

Further, the evidence shows that the liquid should be passed on to the filter fairly evenly over its whole surface, so that the suspended solids may, as far as practicable, be spread over the whole surface and prevented from entering the bed. Harding, 7051. *et seq.* Ross and Pickles, 2077. Harrison, Fowler, 22799. Wike, 23565. Wilkinson, 24920.

109. With a view to avoiding nuisance, the feed channels have, in some few cases, been placed slightly below the surface of the material, and no doubt the smell from the beds has been thereby lessened. But beds fed in this way would, we think, require more frequent attention to prevent clogging.

In one or two cases upward filling of contact beds has been suggested for a similar reason. This method of filling would, no doubt, lessen the risk of nuisance, but the difficulty of maintaining the capacity of beds worked in this way would be serious.

Automatic Gear.

110. We have had many opportunities of studying the use of automatic apparatus for filling and emptying contact beds, and we have received evidence from several witnesses who have had considerable experience of these devices.

Our own observations and the experience of others show that it is not possible to rely entirely on automatic apparatus for sewage works, although within certain limits it may be advantageously used with considerable saving of labour.

In the case of large sewage disposal works, where men are always available, we consider that it would usually be inexpedient to provide automatic plant. It is liable to get out of order, it does not adapt itself to variations in volume and strength of sewage, state of beds, etc., and generally it is preferable to work the beds by manual labour, where such labour is at hand.

At Manchester, automatic gear was given a careful trial, with a view to its ultimate adoption, if successful. It had, however, to be abandoned, and in reference to this Dr. G. J. Fowler stated :—

"I have had considerable experience of these devices, both on the experi- "mental and working scale at the Davyhulme works, and also at the Withington "works. My experience leads me to think that in large works, where skilled "supervision must be provided in any case, there is no advantage in their use. Fowler, 22800.

"In small works I think some simple mechanism is useful, chiefly on "economic grounds, but it should not be left without some attention, if pos- "sible, at least once a day. In small works, with the filtering area divided into "few units, great fluctuations may occur in the cycle unless some arrangement "of dosing tank is provided, or storage in the main tank (septic or other). These "fluctuations may be harmful by causing the time of filling to be too prolonged, "with consequent curtailment of the resting period. The chief difficulty, how- "ever, is the constant variation in the water-holding capacity of the beds and "in the permeability of the surface, causing pondage and irregular working."

We may also refer to the evidence of Messrs. Raymond Ross and Pickles in regard to to the Burnley works. They stated :— Ross and Pickles 20778.

"We have not used any automatic apparatus for filling or discharging. "The reasons which have led to the exclusion of automatic apparatus are as "follows :—

(1) "They are very liable to get out of order, and consequently it is necessary "to have a man always on the watch to see that they are working properly. "As the attendance of one man is all that is required at our works "to control the valves, no saving of wages would be effected, but there "would be considerable increase in capital outlay, as all the appliances "are expensive to instal, and, we think, costly to maintain.

(2) "Automatic apparatus takes no notice of the condition of the bed, which, "in our opinion, is a matter of considerable importance.

(3) "Where the flow of sewage varies, it is desirable to be able to bring the "larger beds into use during the time of the greatest flow, so that their "period of filling may approximately equal that of the smaller beds. This, "we consider, is best accomplished by hand control."

Similar evidence was given by other witnesses.

In the case of small sewage works, however, where labour would not always be available, automatic gear for filling and emptying the beds would often effect considerable saving. Where automatic gear is provided, proper arrangements should be made for the treatment of storm water or sewage overflow arising from a breakdown in the gear. In no case can personal attention be dispensed with entirely.

Loss of Capacity of Contact Beds.

111. The loss of capacity of contact beds is undoubtedly a serious drawback to their efficiency. The evidence shows that the loss chiefly depends upon the following factors:—

(1) Disintegration of the filtering material.
(2) Consolidation of the filtering material.
(3) Deposition of colloidal matter.
(4) Growth of organisms.
(5) The volume of liquid passed on to the bed.
(6) Insufficient rest.
(7) Inefficient drainage.
(8) The amount of suspended matter in the liquid passed on to the bed.

(1) *Disintegration of the Filtering Material.*

112. In the experiments made by Colonel T. W. Harding and Mr. W. H. Harrison at Leeds, the material in nearly all the contact beds was found to have disintegrated considerably.

One of the first of these experiments related to the treatment of crude sewage on contact beds, filled with particles of coke over 3 inches in diameter. This experiment lasted from October 2nd, 1897, to September 8th, 1898, and the coke, in both the primary and secondary beds, suffered considerable disintegration. When the experiment was completed, the material in the primary beds was taken out and only that coke replaced which could not pass through a $1\frac{1}{2}$ inch mesh. Colonel Harding and Mr. Harrison computed the volume of coke rejected in this way at 45·25 per cent. They concluded that if a material could have been used which was not liable to degradation, probably one-third of the loss of capacity would have been avoided.

In the clinker beds, crude sewage, chemically precipitated sewage, and septic tank liquor were treated, and in the case of these beds, also, considerable disintegration took place.

At Hartley Wintney, where soft furnace clinker was used, we observed that the material had disintegrated considerably after five years' work, and we came to the conclusion that this was one of the chief causes of loss of capacity of contact beds at that place.

At Burnley, where a large area of contact beds has been in use for some years, it has been found that the disintegration of the material has caused a considerable loss of capacity. The experience of Burnley, however, has shown that much of the material which has broken down in primary beds may be used with advantage in secondary beds, and that beds which are filled with old material, after it has been washed and re-screened, do not lose capacity so rapidly as beds constructed of new material.

The experience of Manchester in regard to the disintegration of material is also of value. The following data have been given to us as representing a typical case:—

Contact bed No. 10 was first brought into use on May 2nd, 1902, the bulk of the material of which it was composed consisting of dry screened boiler clinker and cinders rejected by a $\frac{3}{16}$ inch mesh. There was also large clinker over the line of drains. After having received 2,578 fillings the bed was stopped, and the whole of the material was washed against a $\frac{1}{4}$ inch mesh sieve. As a result of this screening, 24·1 per cent. of the material was found to be too small to go back into the bed. About two-thirds of this was $\frac{1}{8}$ to $\frac{1}{4}$ inch in size, and was available for the surface of the secondary beds. The actual loss of material, after allowing for the re-use of the material on secondary beds, was estimated by Dr. Fowler at about 8 per cent. to 10 per cent. of the original material.

At Newton-le-Willows, the material (furnace clinker) in all the contact beds at the central works was taken out and re-screened after six years' use. In June, 1900, when the beds were first brought into operation, the material consisted of particles from $\frac{1}{2}$ inch to 2 inches diameter. As a result of the re-screening, which took place between March and September, 1906, Mr. Arthur Bowes, the Surveyor to the Newton-in-Makerfield Urban District Council, estimated that about 25 per cent. was too small to be used again.

At Andover, a bed which was under observation by Mr. R. W. Knapp, was first brought into use on August 13th, 1901, the bulk of the material (hard furnace clinker) being, at that time, from $\frac{1}{8}$ inch to $\frac{1}{2}$ inch diameter. In August, 1905, the bed was stopped and the material taken out and riddled, with the result that only 75 per cent. was found to be still $\frac{1}{8}$ inch to $\frac{1}{2}$ inch in diameter. The remainder had become too small to go back into the bed.

At Oswestry, where ordinary house cinders were used in the primary beds, considerable disintegration took place after about six years' working.

These, and other experiments, leave no room for doubt that a considerable proportion of the loss of capacity of contact beds is due to the disintegration of the material of which the bed is formed.

(2) *Consolidation of the Filtering Material.*

113. Consolidation of the material usually accompanies its disintegration, the small broken pieces becoming washed into the interspaces of the bed. The same thing takes place where the separate fragments of material in a bed are of unequal size.

In the Leeds experiments it was found that contact bed No. 8, treating septic tank liquor, had its capacity reduced within six months from 29,500 gallons to 10,700 gallons, and this notwithstanding that the material below the upper 2 inches was still comparatively clean.

The bed was rested for six weeks, and the material turned over, with the result that on restarting the capacity was found to be 26,900 gallons. The material in this bed was furnace clinker of $\frac{1}{8}$ inch to $\frac{3}{8}$ inch diameter.

Much the same result was noticed during the filtration of lime-precipitated liquor at Leeds in a contact bed. The original water capacity of this bed, on March 24th, 1899, was 55,700 gallons; on October 20th, 1899, after rather over seven months' working at three fillings per 24 hours, it had fallen to 21,600 gallons. Here again the material (clinker of $\frac{5}{8}$ inch to 1 inch diameter) below the upper few inches was found to be fairly clean, though much consolidated.

It was concluded that the loss of capacity in both cases was due very largely to consolidation of fine material of uneven size, and our own observations of these beds bear this out.

In another case—Hampton—where very much finer material was used, the same thing was observed. Tertiary bed No. 2, composed of boiler furnace clinker under $\frac{1}{4}$ inch diameter, including dust, after being in use for five years, became so consolidated that much difficulty was experienced in getting the secondary bed effluent into it. The bed was then simply turned over, and a considerable increase of capacity resulted. From the appearance of the material before it was turned over (which although clean, was closely bound together), it was evident that the greater part of the loss of capacity was due to the consolidation of the material rather than to clogging from suspended matter.

Beds of very fine material, as in this case, are undoubtedly more liable to consolidation than beds of medium sized or large material. In some beds of the same kind at Devizes, we observed that the fine material (which also included dust), although fairly clean, was so closely bound together that the liquid of one filling had not time to run away before the next filling was due, with the result that putrefaction set up in the body of the bed.

(3) *Deposition of Colloidal Matter.*

114. The extent to which colloidal matter affects the capacity of filter beds has not been fully investigated, but we are satisfied that in some cases it is serious. Dr. Fowler was, we believe, one of the first to investigate the matter in this country, and it has recently been the subject of investigation by Dr. Owen Travis at Hampton, and Messrs. O'Shaughnessy and Kinnersley at Birmingham.

(4) *Growth of Organisms.*

115. If a piece of clean filtering material is taken out of the interior of a matured contact bed and scraped, its surface will be found to be covered with a jelly-like material, which, under the microscope, is seen to contain enormous numbers of bacteria. This material possesses the power of absorbing oxygen rapidly and liberating carbon dioxide. It is probable that it is the living matter bound up in this jelly which gives the bed power to break down and oxidise the organic matter of impure liquids, but little is known about its precise nature and manner of action.

Several witnesses have expressed the view that the growth of organisms is one of the causes of loss of capacity in a contact bed.

In regard to this point Dr. Fowler stated :—

Fowler, 22803.

"This (growth of organisms) is at once the cause of increased efficiency in "the bed, and of loss of capacity. On examining the material of a contact bed "in active condition, every piece is seen to be coated over with a slimy growth. "If this is removed it soon dries to a stiff jelly, which can be cut with a knife. "Under the microscope masses of bacteria and zooglœa will be found to be "present. If placed in a tube containing air, and connected with a manometer, "the jelly will rapidly absorb all the oxygen and produce carbon dioxide.

"This action will sometimes produce a vacuum of several inches of mercury. "There is little need, therefore, to force air into a bed, as the natural interchange "of gases which takes place is sufficient for adequate aeration. As a matter "of fact, there is always a large amount of oxygen to be found at the bottom of "a bed in good condition. The behaviour of the bacterial jelly appears to afford "the clue to the successful working of bacteria beds. By working them at a high "speed—*i.e.*, filling them frequently in the day, without long periods of rest— "the effluent may remain good, but the bacterial growth so rapidly increases "that the bed becomes too spongy, and will not allow the water to drain away. "Here, too, is the explanation of the fact that, within certain limits, decrease of "capacity is accompanied by increase of efficiency.

"This decrease of capacity may, however, become so great as to outweigh "the advantage of increased efficiency. A long period, say one or two weeks' "rest, must then be given to the bed.

"These rests should not exceed a fortnight at most, as the bed then tends to "dry up, and the activity of the organisms diminishes.

"It is therefore important that the decrease of capacity should not be "allowed to become excessive before resting, or it may not be possible to com- "pletely recover the loss during the time of rest."

(5) *The Volume of Liquid passed on to the Bed.* (6) *Insufficient rest.* (7) *Inefficient drainage.*

116. It is evident that, for physical reasons alone, the working capacity of a contact bed must be influenced to some extent by the actual volume of liquid treated. If, for instance, two exactly similar contact beds, filled with unmatured material of the same size, are fed with pure water, one being given eight fillings and the other two fillings per day, the former, although not losing capacity in the absolute sense, will take rather less water at each filling than the latter, owing to the less time allowed for drainage between the fillings.

We do not suggest that the water held in a clean and unmatured bed by capillary attraction, after the bed is emptied, has a serious practical effect upon the working capacity of a bed; but with a matured contact bed containing jelly-like masses of bacteria as well as sewage suspended matter in a very spongy state, the time allowed for drainage becomes a question of importance, and the volume of liquid dealt with, in practice, affects the capacity of contact beds. A rather larger quantity of filtering material would, for instance, be advisable at a sewage works, where two volumes of weak sewage were to be treated in contact beds, than at another where one volume of sewage, of twice the strength, had to be dealt with.

117. The value of rest to a contact bed in helping it to maintain its water capacity is well known. We may cite two cases; one relating to the treatment of a manufacturing sewage (Leeds), and the other to the treatment of a purely domestic sewage (Hampton).

Leeds.—During the experiments upon the filtration of Leeds crude sewage, the primary bed, which started on October 2nd, 1897, with a water capacity of 83,000 gallons, had been reduced by February 2nd, 1898, to 45,000 gallons capacity. After a fortnight's rest its capacity was again measured, and found to be 56,000 gallons, or an increase of 11,000 gallons.

A similar increase of capacity followed subsequent rests.

Hampton.—At Hampton, No. 2 primary bed started in the early part of 1899 with an estimated water capacity of approximately 43,500 gallons, and was found on February 3rd, 1903, to have a capacity of only 8,637 gallons. On September 23rd, 1904, after a fortnight's rest, its capacity had risen to 12,965 gallons.

A gain of capacity in contact beds, by giving them rest, has been commonly noticed ever since they were first brought into use by Mr. Dibdin. For some time the cause of the gain was assigned to the biological digestion of the suspended matter caught in the material of the filter. A part of the gain in capacity which takes place during rest is no doubt due directly to this cause; but we think that much is due indirectly to the digestion tending to make the organic matter in the bed of a more granular and less spongy character. The ultimate gain in capacity is due to the water being able to drain away. It was shown, by Colonel Harding and Mr. Harrison at Leeds, that the deposit in a primary contact bed which had caused that bed to lose capacity contained something like 90 per cent. of water.

It must be remembered, however, that the gain in capacity which results from the resting of a clogged bed is generally only of a temporary character, a short rest of, say, a fortnight, serving for little more than to shrivel up the spongy and gelatinous matter in the interspaces of the bed. In many cases it has been observed that such matter returns to its original spongy state soon after the bed has been restarted. If a bed could be rested for a very long time, the sewage matter would become permanently granular through oxidation; but this is not practicable on a large scale, and as it would possibly result in the bed losing its maturity, it is important not to allow a contact bed to become so seriously clogged as to necessitate a prolonged rest.

As we have already intimated, it is important that the drainage should be efficient. Unless a bed is so constructed as to allow of proper drainage it will inevitably suffer rapid loss of capacity. Moreover its oxidising power will be impaired.

(8) *Suspended Matter in Liquid.*

118. Where the greater part of the suspended matter in the incoming liquid is allowed to find its way into the body of the material, the loss of capacity tends to vary in direct proportion to the amount of suspended solids in the sewage or tank liquor which is being treated. If very fine material is used in a bed, or if a bed of medium sized material is coated with a layer of very fine material, a large proportion of the suspended matter is caught upon the surface.

There is a large amount of experience showing that primary contact beds lose capacity at a greater rate than secondary beds, and we think there can be no doubt that this is largely due to the fact that the primary bed usually receives considerably more suspended matter. At the same time the facts that the suspended matter in a primary bed effluent is of a somewhat different character to the suspended matter in a tank liquor or a crude sewage, and that there is less colloidal matter in a primary bed effluent, would, to a lesser extent, account for the difference.

119. The following table shows the loss of capacity, per million gallons of liquor treated, at places which have been under our own observation, where septic tank liquor was treated on *primary* contact beds of medium sized material :—

Place.	Suspended matter in the liquor treated. (Hourly samples taken in dry weather.)	Age of beds in months.	Average number of times beds were filled per day.	Estimate of total number of gallons treated.	Loss of capacity in gallons.	Rate of loss of capacity per million gallons.
Guildford - - -	15·9	46	2·0	223·8 millions	108,794	486 gallons
Exeter (Main Works)	12·5	37	1·62	2,056 millions	750,750	365 gallons
Andover - - - -	11·1	38	1·2	96 millions	79,600	828 gallons
Exeter (Old Works) -	8·2	109	1·64	196·2 millions	39,670	202 gallons
Slaithwaite - -	7·1	84	2·0	226·2 millions	33,755	149 gallons

With the exception of Andover, the loss of capacity per million gallons was, approximately, in proportion to the amount of suspended matter put upon the beds. The high rate of loss of capacity at Andover is accounted for by the fact that the material in the beds disintegrated to such an extent as to cause the surface level to sink considerably.

120. In connection with this matter we may refer to our Accrington * experiment. In that experiment two pairs of contact beds were run side by side for rather more than a year, one pair receiving two fillings per day of septic tank liquor, and the other pair receiving four fillings per day of the same tank liquor diluted with an equal volume of water. Both beds, therefore, received equal aggregate amounts of suspended matter. The capacity measurements throughout this time were as follows :—

	Primary bed treating septic tank liquor undiluted.	Secondary bed treating septic tank liquor undiluted.	Primary bed treating septic tank liquor diluted.	Secondary bed treating septic tank liquor diluted.
	Gallons.	Gallons.	Gallons.	Gallons.
May 3rd, 1905 (before starting) -	1,170	1,035	1,185	1,070
October 25th, 1905 - - -	810	1,080	770	940
June 6th, 1906 - - - -	735	1,030	780	950

During this period, therefore, the two primary beds (of coarse material) lost capacity at, approximately, the same rate, the loss (435 gallons) in the primary bed treating the one volume of undiluted tank liquor being slightly greater than the loss (405 gallons) in the primary

* *See* pp. 110-117 and also Appendix IV.

bed treating the two volumes of diluted tank liquor. Even this small difference is explained by the fact that rather more than the proper proportion of suspended matter was, on the average, washed out of this bed, as the primary bed treating diluted tank liquor was emptied twice as frequently as the other. The average suspended matter in the effluent from the primary bed treating the one volume of undiluted tank liquor during the period was 6·3, and in the effluent from the primary bed treating the two volumes of diluted tank liquor 3·6 parts per 100,000. As the two primary effluents were discharged on to the two secondary beds (of fine material), the effect of the suspended solids was shown in these also, the difference in rate of loss of capacity being still further accentuated there by the fact that the secondary bed treating diluted tank liquor, unlike the primary bed, retained rather more than its proper proportion of suspended matter. The suspended matter in the effluent from the secondary bed treating undiluted tank liquor averaged 4·2, and in the effluent from the secondary bed treating diluted tank liquor 1·7 parts per 100,000. It is obvious, therefore, that, at any rate, the greater part of the disproportionate loss of capacity in the secondary bed treating the two volumes of diluted tank liquor was due to the fact that this bed received rather more suspended matter than the other secondary bed, and also held rather more back.

In June, 1906, the method of working the beds was altered. One set of beds then received two fillings per day of septic tank liquor undiluted, and the other set two fillings per day of septic tank liquor diluted with an equal volume of town's water. The first pair therefore received twice as much organic impurity, *including twice as much suspended matter*, as the second.

As will be seen from the following capacity measurements, the primary beds receiving the undiluted tank liquor soon began to lose capacity.

	Primary bed treating septic tank liquor undiluted.	Secondary bed treating septic tank liquor undiluted.	Primary bed treating septic tank liquor diluted.	Secondary bed treating septic tank liquor diluted.
	Gallons.	Gallons.	Gallons.	Gallons.
June 6th, 1906 - - -	735	1,030	780	950
February 18th, 1907 - -	640	970	750	890

During this second period of working, the primary bed receiving one volume of undiluted tank liquor lost 95 gallons of capacity, while the primary bed receiving one volume of diluted tank liquor lost only 30 gallons. The average quantities of suspended matter entering and leaving the two primary beds for the period were as follows :—

	Primary bed receiving one volume of septic tank liquor undiluted.	Primary bed receiving one volume of septic tank liquor diluted
	Parts per 100,000.	Parts per 100,000.
Average quantity of suspended matter going on to bed -	14·1	7·3
Average quantity of suspended matter coming out of bed	7·7	3·7

It might have been expected that the loss of capacity in the secondary bed treating the diluted tank liquor would have been only half the loss of capacity in the secondary bed treating the undiluted tank liquor. It will be seen, however, that the loss of capacity in the secondary beds was the same in each case. The suspended solids in the effluent from the secondary bed treating the undiluted tank liquor averaged 5·0 parts per 100,000,

but the suspended solids in the effluent from the secondary bed treating the diluted tank liquor, so far as we could judge from the centrifuge figures (which, however, can only be taken as approximate), were about one-third of this, the actual figures being as follows :—

—	Secondary bed receiving one volume of septic tank liquor undiluted.	Secondary bed receiving one volume of septic tank liquor diluted.
	Parts per 100,000.	Parts per 100,000.
Average quantity of suspended matter going on to bed -	7·7	3·7
Average quantity of suspended matter coming out of bed	5·0	1·7 approx.

In both periods of working (May 3rd, 1905, to June 6th, 1906, and June 6th, 1906, to February 18th, 1907), the loss of capacity in every one of the four beds (primary and secondary) ran concurrently with the amount of suspended matter held back by the bed.

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ampbell, 21665. arrison, 22016. alentine, 22462. ike, 23571.

121. A contact bed loses capacity rapidly at first, and subsequently at a diminished rate. Evidence in regard to this was given by Mr. Campbell, of Huddersfield, Mr. Harrison, of Leeds, Mr. Valentine, of Oldham, and Mr. Wike, of Sheffield, and others.

At Huddersfield the period of rapid loss in the case of the primary bed was within the first five months, and in the case of the secondary bed within the first twelve months. At Leeds it seems to have been within the first nine or twelve months ; at Oldham within the first twelve months ; at Sheffield, for the primary contact bed, within the first six months, and for the secondary bed, within the first twelve months.

We may also refer to the experimental Roscoe beds at Manchester which, after losing capacity for some time, eventually reached an equilibrium, and from then onwards maintained a constant water capacity so long as the suspended matter accumulating on the surface was periodically removed. These beds were filled with chemically precipitated sewage, which usually contains less colloidal matter than settled sewage or septic tank liquor.

It does not appear that any rule can be deduced as to the length of the period during which capacity is lost rapidly. It would, no doubt, partly depend both upon the rate of filtration and upon the amount of suspended matter reaching the bed.

How to Diminish the Rate of Loss of Capacity.

122. The capacity of a contact bed is best maintained by :—

Preventing as far as possible the access of suspended or colloidal matter to the bed ;

Using materials which are not liable to disintegrate ;

Using for the body of the filter material of even size, and in the form of cubes or spheres rather than flakes.

Allowing thorough and efficient drainage ;

Not over-working the bed ;

Giving periodical rests ;

Filling and emptying the bed in such a way as not to disturb the material.

The access of suspended matter to a contact bed is, in most cases, the chief cause of loss of capacity, and no doubt the rate of loss can be greatly lessened by carefully eliminating the suspended solids from the sewage before filtration.

Some small experimental filters at Kingston, fed with precipitation liquor, which had been produced by the "A.B.C." process, maintained their capacity in a remarkable manner. By this process a tank liquor is obtained containing a very small amount of suspended solids.

Even the best known means for removing the suspended matter by preliminary treatment does not get rid of it entirely, and it is generally advisable to provide a layer of fine material in the upper few inches of the bed, so as to prevent, as far as possible, the suspended matter from gaining access to the body of the bed.

Experience may show that it is economical to adopt some intermediate method of removing suspended matter from tank liquors. At Birmingham, Dortmund tanks are used for this purpose, and at Leeds, Chester, Ilford, and Guildford, mechanical straining has been tried. The latter method, however—as carried out at those places—has not been satisfactory.

The question whether it is more economical frequently to wash or renew the material in contact beds, or to remove the greater portion of the suspended matters from the liquor before it is treated, and to wash the beds less frequently, depends primarily on local circumstances.

Of the preliminary processes for removing suspended matter from sewage, chemical precipitation followed by either quiescent or continuous flow settlement is undoubtedly the most efficient of those at present known ; but it involves a larger annual cost in most cases than settlement by means of settling or septic tanks, and there is a larger quantity of sludge to be dealt with.

Washing of Filtering Material.

123. The evidence shows that in many cases it is practicable and economical to wash filtering material which has become clogged. The cost varies according to local circumstances, and the following instances may be cited.

At *Burnley*, the material of several clogged beds was washed by means of an inclined rotary screen, 10 feet by 4 feet, fixed at a suitable elevation and so constructed as to be easily capable of removal from bed to bed as required. The arrangement admitted of washing, grading, and screening the material (clinker) : the washing was effected by the tank effluent : and the power was supplied by a portable engine. Pickles and Ross 20785.

The cost of these operations was at the rate of 1s. per cube yard of material, which covered excavating, packing troughs, wheeling, and screening and washing not only the material excavated but also the additional material required to take the place of the old material rejected (about 10 per cent.) and filling it into the bed.

At *Leeds*, Mr. Harrison, the chemist to the Corporation, washed 1,020 cubic yards of material, by hand labour with screens and a heavy flow of water, at a cost of 2s. 5d. per cube yard. Harrison, 22017.

At *Manchester*, the washing of filtering material has been done on a very large scale, and is carried on continuously. The method employed is to pass the material from a sump to a jigging screen of $\frac{1}{4}$-inch mesh, over which are fixed a series of horizontal water sprayers. The material rejected by this screen is further graded by passing over a fixed 2-inch mesh screen. The material which passes through the $\frac{1}{4}$-inch screen falls on to an inclined fixed screen of $\frac{1}{8}$-inch mesh. All material above $\frac{1}{4}$-inch is replaced in the primary filters ; that between $\frac{1}{4}$-inch and $\frac{1}{8}$-inch will be used for the surface of the secondary contact beds, when these are constructed. Settled sewage is the liquid used in the washing.

The total cost of removing, washing, screening and replacing in beds and making up to original level with new material at Manchester, is 1s. 6d. per cube yard. This does not include cost of washing machinery.

At *Birmingham*, 20,000 cubic yards of material were dealt with in the following manner: the material was dug out of the beds by manual labour and conveyed in tip wagons to a high platform by an electrically-driven winch; it was then passed through revolving screens and simultaneously washed with sewage.

The cost of removing, washing, screening and replacing material in the beds was at the rate of 11d. per cube yard. With the additional material required to make up to original level of bed, the total cost was 2s. 2½d. per cube yard. This does not include the cost of the washing plant.

At the *Beddington* and *South Norwood* sewage works of the Corporation of Croydon, filtering material has been washed on a large scale. The work was done by hand labour, and the cost of washing and replacing the material in the beds was approximately 1s. 2½d. per cube yard at Beddington, and 1s. 6d. per cube yard at South Norwood.

At *Andover*, the cost of washing and replacing material by hand labour, with a special apparatus devised by Mr. R. W. Knapp, the surveyor, was about 2s. 4d. per cube yard. This covered the initial cost of the washing apparatus.

At *Hampton*, washing is effected by means of a machine driven by compressed air. The cost of removing old material, screening, washing and replacing in bed, and providing new material to make up deficiency (25 per cent.), is 1s. 9¾d. per cube yard.

Campbell, 21552.

At *Huddersfield*, the borough engineer found that the cost of washing material was not less than 4s. 6d. per cube yard. No information was given as to the method employed.

124. The cost of washing, etc., at the several places mentioned (except Huddersfield) is summarised in the following tables:—

MATERIAL WASHED BY MACHINERY.

Name.	Nature of liquid treated by beds.	Average amount of suspended matter in liquid going on to beds (parts per 100,000).	Time beds had been in use.	Nature and size of material.	Quantity of material dealt with (cube yards).	Cost per cube yard of washing operations, including making beds up to original level with new material, but excluding cost of washing plant and maintenance charges on same.	Cost per acre, 3 feet deep, of washing operations, including making beds up to original level, with new material, but excluding cost of washing plant and maintenance charges on same.	Percentage of original material replaced in bed.	Cost per cube yard of new material.	Remarks.
						s. d.	£ s. d.			
Burnley - -	Septic tank liquor	5 to 6	3½ years	Clinkers (⅛″ to ½″)	3,350	1 0	242 0 0	60 per cent.	—	
Manchester -	Septic tank liquor	5 to 6	4 to 5 „	Clinkers (medium to coarse)	A very large quantity	1 6[b]	363 0 0	70 per cent. to 75 per cent.	½″ to 2″—2s. 6d. to 3s.; over 2″ 3s. to 3s. 6d.[a]	[a]Delivered in the beds. [b]Final disposal of rejected material not included in this figure.
Birmingham -	Septic tank liquor	—	4 „	Clinker, Coke (fairly coarse)	20,000	2 2½	534 0 0	80 per cent.	6s. 6d.[c]	[c]New material—broken stones.
Averages - -	—	—	4 years	—	—	1 6¾	380 0 0	71·25	—	

MATERIAL WASHED BY HAND

Name.	Nature of liquid treated by beds.	Average amount of suspended matter in liquid going on to beds (parts per 100,000).	Time beds had been in use.	Nature and size of material.	Quantity of material dealt with (cube yards).	Cost per cube yard of washing operations, including making beds up to original level with new material, but excluding cost of washing plant and maintenance charges on same.	Cost per acre, 3 feet deep, of washing operations, including making beds up to original level, with new material, but excluding cost of washing plant and maintenance charges on same.	Percentage of original material replaced in bed.	Cost per cube yard of new material.	Remarks.
Hampton - -	Crude sewage	48·5	2 to 4 years.	Clinker (medium to coarse)	260	2 6¾	620 0 0	Primary beds 75 per cent. Secondary beds 65 per cent.	—	
South Norwood -	Screened sewage	Not known	4 „	Burnt ballast (medium to coarse)	1,640	1 6	363 0 0	—	—	
Beddington -	Septic tank liquor		3¾ „	Flint and clinker (coarse)	15,377	1 2½	292 0 0	No appreciable loss with flints.	—	
Andover - -	„ „	11·10[e]	4 „	Clinker (½″ size free from dust)	490	2 4[e]	564 0 0[d]	—	—	[d]Including cost of plant.
Leeds - - -	—	—	—	—	1,020	2 5	584 0 0	—	—	[e]Based on the three sets of average samples, taken October, 1904.
Averages - -	—	—	About 4 years	—	—	2 0	484 12 0	—	—	

It should be added that washed material has an enhanced value for filtration purposes, due in great measure to the fact that the softer and more friable portions of the original material, which have become broken down, are eliminated in process of washing.

125. We may mention here that other plans for restoring contact beds which have become clogged have come under our observation at Hartley Wintney, Hendon, and Oswestry.

At *Hartley Wintney* the contact bed material (gas works clinker) was simply turned over. The amount dealt with was 679 cube yards; one man was employed; and the cost amounted to only 5½d. per cube yard.

The beds had been in use about four and a half years when the material was turned over.

The increase in capacity due to this process was, however, quickly lost again.

At *Hendon*, the ballast on the percolating beds was reburned. The cost amounted to 3s. 6d. per cube yard; but this covered the sifting out of the small material, wheeling out the fine stuff and spreading it, and relaying drains, etc. The beds had been in use for sixteen years.

At *Oswestry*, the old material of the beds was so disintegrated as to render washing impracticable, and there was sufficient new material (screened cinders) lying on the site. The old material (cinders) was therefore discarded and the beds filled with new material. The quantity dealt with was 1,550 cube yards, and cost of removing and renewal amounted to 2s. 7½d. per cube yard. The beds had been in use for about four years.

Filtering Material in Contact Beds.

126. The materials in general use for contact beds are clinker and coke, and experience of other materials is not very great.

With percolating filters, however, many different materials have been used, and although the actual working of percolating filters is different from that of contact beds, the results are, to a large extent, applicable. At York, a quantitative experiment with septic tank liquor was made by us on a circular percolating filter 7 feet 8 inches deep and constructed in four segments—one of clinker, one of coke, one of slag, and one of broken brick—the material in each case being broken and riddled as nearly as possible to the same size; the bulk of the clinker was, however, distinctly smaller than the other three materials. The results showed that the best effluent was obtained from the clinker segment, that the coke and slag segments gave very similar effluents, but not quite so good as the effluent from the clinker segment, and that the effluent from the broken brick segment was lowest in the scale of purity. All four effluents were of good quality.

Watson 25004. At Hendon the late Colonel Ducat obtained a better effluent from clinker in a percolating filter 8 feet deep than from pebbles in the same bed. At Birmingham Mr. J. D. Watson found that for percolating filters gravel has too smooth a surface. Dr. George Reid also stated in evidence that "any hard, non-friable material of irregular shape and not too smooth a surface, and one which is not liable to disintegrate is satisfactory as a filtering medium for percolating filters." Fowler, 22794.

The experience at Manchester, with regard to contact beds, has been that hard furnace clinker is the best material, being vesicular and yet permanent. Dr. Fowler, however, expressed the opinion that broken Staffordshire bricks, saggars and gravel, if properly sized, should do equally well.

It will be seen from the evidence that many witnesses have stated that substances like gravel, flints, or broken granite, are suitable as a filtering medium, but that, in most cases, they have expressed a decided preference for the use of those materials which present the roughest and most irregular surfaces, such as clinker, coke, and saggars.

So far as our own experience goes, we should prefer, as a general rule, to use coke or good clinker in a contact bed in preference to other materials.* It is true that there is some evidence to the effect that rather better effluents can be obtained from contact beds of coke than from contact beds of clinker, but we think that this advantage is balanced by the tendency of the lighter material, coke, to shift slightly every time the bed is filled, and therefore to be more liable to disintegration.

* Broken "saggars" might be equally good, but we have had no experience of this material in contact beds.

In the choice of a filtering medium local circumstances must, of course, be taken into account. For example, there may be places at which a somewhat inferior material may be obtained at a very low price, and where it would be cheaper to renew the beds more frequently, or to provide a larger area of beds, than to pay the higher price for better material.

Probably most materials will purify sewage, but a larger quantity of smooth than of vesicular material would be required to produce equal purification.

127. Mr. W. J. Dibdin has lately advocated the use of large slabs of slate in primary contact beds, the horizontal layers of slate being separated from one another by cross pieces. He claims that crude sewage can be purified to a considerable extent in such beds, and that the sludge which accumulates in them can be periodically flushed out with water. Up to the present time we have had no experience of primary contact beds constructed in this way, beyond a single visit to Devizes where such beds were in use for the treatment of screened sewage. As a result of our inspection of the beds at Devizes, we came to the tentative conclusion that primary beds containing large slabs of slate must be regarded more as preliminary settling or septic tanks than as contact beds. As to the feasibility of washing such beds out, or as to the amount of digestion of sludge which takes place in them, we are unable to express an opinion.

Size of Material.

128. The smaller the size of material used in a contact bed the greater is the internal surface area exposed, and consequently the more intimate is the contact of the liquid with the material, the greater the purification, and the more efficient the arrest of the suspended and colloidal matter.*

The efficiency of a contact bed, however, depends very largely upon the admission of air to all parts of the filter during the time the bed is resting empty. Thorough and rapid drainage is therefore of the utmost importance.

For this reason, it is important that the material in a contact bed should not be *too* small, especially if the liquid to be treated contains an appreciable quantity of suspended matter, as some of this suspended matter will undoubtedly find its way into the interstitial spaces and prevent proper drainage of the bed. This was found to be the case with the fine beds at Devizes and Hampton.

At Devizes the contact beds were composed of very fine clinker broken to a diameter from ¼-inch downwards and including dust. Shortly after the beds were brought into operation, working at a rate of three fillings per day, it was found, on digging down into them, that the liquid of one filling had not drained away from the beds when the time for the next filling arrived. On examination it appeared that, although there was not actually a large quantity of sewage solids admixed with the filtering material, enough was present to bind the whole together, so that the bed drained away very slowly.

At Hampton the tertiary contact beds were composed of furnace clinker of ¼-inch or less, including dust, and after five years' work the material had settled into an almost solid mass, and the beds could only be filled with difficulty. The material, when turned out, presented a very similar appearance to that at Devizes, being closely bound together, although mixed with only a small proportion of sewage suspended matter.

129. If the liquid to be treated contained no suspended or colloidal matter, material as fine as medium sand would probably give the best results; but if crude sewage were to be put upon this sand, the surface would become so clogged with sewage sludge in two or three fillings that the bed would be practically useless. The top layer would then have to be removed, or the bed would have to be rested until the sludge upon the surface had dried sufficiently to be raked off. Even if the top sand were constantly removed and replaced, it would be found, as at Hampton and Devizes, that some particles of suspended matter would penetrate into the interior of the bed, and that eventually the drainage of the bed would become defective.

* Note.—See Biltz and Kröhnke, Berichte, vol. xxxvii., p. 1745; Fowler and Ardern, J. Soc. Chem. Ind., vol. xxiv., p. 483 (1905); Jones and Travis, Proc. Inst. C.E., vol. clxiv., paper 3599, p. 32 (Jan. 1906); O'Shaughnessy and Kinnersley, J. Soc. Chem. Ind., vol. xxv. (April, 1906); Johnston, J. Roy. San. Inst., vol. xxvii., p. 10 (1906).

In deciding upon the size of the material to be used, the amount of suspended matter in the liquid to be treated, must be considered. As a general rule, the greater the amount of suspended matter in the liquid the larger the material should be.

With a crude sewage containing 40 parts per 100,000 of suspended matter, the material will probably have to be from 3 inches upwards in diameter, and even then sludge will accumulate on the top.

With a septic tank liquor containing 8 to 10 parts per 100,000 of suspended matter, material of a diameter from $\frac{3}{8}$ to $\frac{5}{8}$ of an inch may probably be used effectively; while with a good precipitation liquor containing from 1 to 3 parts of suspended matter, the best results will probably be obtained from material as fine as $\frac{1}{4}$-inch diameter.

130. It is, however, impossible to make any but the most general statement as to the most suitable size of material for contact beds, as, in some cases, there may be special circumstances which affect the question, such as the character of the suspended matters, or the smoothness of the filtering material. The sizes we have suggested are based on the evidence which we have received and also on our experience of contact beds at the places named in the following statement:—

	Suspended matter in the liquor treated (approximate figures).	Nature of material.	Size of the material in the contact beds.
Crude Sewage.	Parts per 100,000.		
Hampton	48·5	Clinker.	Above 4″ diameter.
Leeds	35·0	Clinker and coke.	Above 3″ diameter.
Newton-le-Willows	30·0	Clinker.	Top 18″—$\frac{1}{2}$″ to $\frac{1}{4}$″ diameter. Body of filter, 2″ to $1\frac{1}{2}$″ diameter.
Withnell	20·0	Clinker.	1″ to $1\frac{1}{2}$″ diameter.
Maidstone	14·0	Clinker.	Above $\frac{3}{4}$″ diameter.
Settled Sewage.			
Oswestry	About 20.	House coke.	$1\frac{1}{2}$″ to $\frac{1}{2}$″ diameter.
Halton	11·0	Clinker and pebbles.	1″ to 2″ diameter.
Septic Tank Liquor.			
Leeds	18·0	Clinker.	$\frac{5}{8}$″ to $\frac{3}{8}$″ diameter.
Guildford	16·0	Burnt ballast.	$\frac{1}{2}$″ to 3″ diameter.
Hartley Wintney	15·0	Clinker.	$\frac{1}{2}$″ to $\frac{1}{8}$″ diameter.
Exeter (Main)	About 14.	Clinker.	$\frac{1}{2}$″ to 1″ diameter.
Andover	12·0	Clinker.	$\frac{1}{8}$″ to $\frac{1}{2}$″ diameter.
Exeter (St. Leonards).	8·5	Clinker and coke.	$\frac{1}{2}$″ diameter.
Slaithwaite	8·0	Clinker.	Top foot—$\frac{3}{8}$″ to $\frac{1}{3}$″ diameter. Body of filter, $\frac{3}{8}$″ to 1″ diameter.
Precipitation Liquor.			
Calverley	12 to 14.	Clinker.	$\frac{1}{4}$″ to $\frac{1}{2}$″ diameter.
Kingston (experimental beds)	2·0	Clinker and coke.	Coke bed, $\frac{1}{4}$″ to 1″ diameter. Clinker bed, $\frac{1}{4}$″ to $\frac{3}{8}$″ diameter.

Grading of Material.

131. From our own observations, and from the evidence, we are of opinion that, as regards the bulk of the material in the bed, grading is not necessary, and that much labour and expense have sometimes been incurred, to very little purpose, in too great a refinement of grading. A certain amount of grading is, however, always necessary. Over the drains of the beds, for instance, material of fairly large size must be laid in order to prevent choking. Again, in order to preserve the life of a contact bed, it is advisable to retain as much as possible of the suspended matter upon the surface of the material, and this seems to be best effected by using fine material for the top 6 inches or so.

We may refer particularly to the evidence on this question which was given by Mr. D. Cameron (2091); Mr. Baldwin Latham (4505); Colonel Harding (7165–6); Dr. P. F. Frankland (9985–6); Mr. Bolton (21145); Mr. J. Kershaw (21464); Mr. Campbell (21655); Mr. Harrison (22008); Dr. Fowler (22795); Mr. Wike (23652); Mr. Wilkinson (24286); Messrs. Willcox and Raikes (26182).

AMOUNT OF SEWAGE WHICH CAN BE TREATED ON CONTACT BEDS.

132. The amount of sewage which can be treated on contact beds chiefly depends on the strength of the sewage, on the quality of effluent which it is required to produce, on the amount of suspended solids in the sewage, and on the size of the filtering material. The question is dealt with in the section headed "General Conclusions as to the Working Power of Different Types of Filter," p. 117.

PERCOLATING FILTERS.

Depth of Percolating Filters.

133. The question of the depth of percolating filters is one of far greater complexity than at first sight appears. At most places the depth has usually been determined by the levels. If plenty of fall has been available, deep filters have been constructed, while at places with little fall, the material has usually been laid out in the form of a shallow filter. In other words percolating filters have usually been constructed as deep as levels would allow. In some cases the advantage of deep filters over shallow filters has even been considered sufficient to justify the adoption of pumping.

It has thus been generally accepted that, in the case of percolating filters, the deeper the material the better the result obtained. That there were good grounds for this conclusion will be seen from the following evidence.

At Accrington, in 1897, Mr. C. J. Whittaker, experimenting upon the depth of filtering material necessary for the purification of open septic tank liquor by means of the Whittaker and Bryant percolating filters, compared the results obtained from filters 6 feet and 9 feet deep, both constructed of the same coarse material and both receiving the same quantity of tank liquor *per square yard.* Mr. Whittaker found that the 9 foot bed gave better purification and higher nitrification than the 6 foot bed.

At Leeds, in the year 1900, Colonel T. W. Harding and Mr. W. H. Harrison, in their experiments upon the continuous filtration of crude sewage, touched upon the same point. In one of these experiments, which lasted for six months, Leeds crude sewage was allowed to trickle continuously through three filters one after another, one object of the experiments being to ascertain the purifying effect of each separate filter. The filters were 3′ 6″, 2′ 6″ and 2′ 6″ deep respectively, so that the total depth of the material, which consisted of coarse coke, was 8′ 6″. The average analyses of the effluents from each filter, from March to June, 1900, were as follows :—

Grains per gallon.

——	Crude Screened Sewage.	First Filter 3′ 6″ deep.	Second Filter 2′ 6″ deep.	Third Filter 2′ 6″ deep.
Free Ammonia	2·36	1·58	1·15	0·83
Albuminoid Ammonia	1·04	0·59	0·43	0·29
Oxygen absorbed from permanganate in 4 hours.	8·90	4·37	2·78	1·93
Nitrogen as nitrates	—	—	—	0·14
Total solids	123·2	87·6	74·0	7·17
Suspended solids	44·2	19·2	7·9	7·7

Another experiment was made by Mr. Carter Bell, at Salford, during the years 1900 and 1901, on the depth of medium-sized material necessary for the purification of Salford precipitation liquor. In this experiment three percolating filters 8 feet, 5 feet, and 3 feet deep, all constructed of medium-sized clinker, received precipitation liquor at the same rate *per square yard.* Typical analyses of the effluent are given by Mr. Carter Bell as follows :—

Grains per gallon.

	Shallow filter 3 feet deep.	Medium filter 5 feet deep.	Deep filter 8 feet deep.
Free Ammonia	2·6	2·4	2·2
Albuminoid Ammonia	0·20	0·18	0·14
Oxygen absorbed from permanganate in 4 hours	1·1	0·8	0·5
Nitrogen as nitrates	0·84	1·10	1·30
Total solids	65·0	66 0	65·0
Koch's gelatine and incubation test	Fairly satisfactory.	Satisfactory.	Very satisfactory.

At Horfield, Mr. F. W. Stoddart, experimenting with two filters of coarse clinker, one 7′ 6″ deep and the other 3′ deep, came to the conclusion that with an equal flow *per square yard* the deep filter gave the better results.

134. There were no doubt many other experiments of the same kind, showing that, when treating the same amount of sewage per square yard, the deeper the filter the greater is the purification effected. These experiments, however, do not show whether it is better to arrange a *given* quantity of material in the form of a deep or of a shallow percolating filter, and so far as we are aware no systematic experiments on the treatment of sewage or sewage liquor upon filters of different depths at equal rates *per cube yard,* instead of *per square yard,* were carried out until our observations were begun at Horfield and Ilford.

Horfield Experiments.

135. At Horfield, experiments were made in the years 1904–5, upon two filters of coarse clinker, one 7′ 5″ deep and the other 3′ deep, upon each of which quantities of Horfield precipitation liquor were treated at approximately the same rate *per cube yard* per day for ten months. Both filters were fed by means of Stoddart trays. The deep filter had a cubic content of 284 cube yards and the shallow filter of 27·56 cube yards.

The results showed that there was little to choose between the two effluents, though on the whole the effluent from the deep filter was slightly the better. At the same time, though the experiments showed that a coarse shallow filter (3 feet in depth) can quite well be made to give satisfactory results in the treatment of a precipitation liquor like that at Horfield, they also indicated that with coarse material, where the levels allow of it, a deep filter is on the whole preferable to a shallow one, especially where a strong liquor is being dealt with, since faults of distribution are toned down more.

Ilford Experiments.

136. At Ilford, a similar experiment with two very small percolating filters fed by means of Stoddart trays was made in 1903–4. The filters had the following dimensions :

Deep filter 12 feet by 9 feet and 6 feet deep.

Shallow filter 12 feet by 9 feet and 3 feet deep.

The material used was coke, from $1\frac{1}{2}''$ to 3″ in diameter. Both filters were fed with septic tank liquor at the rate of 125 gallons per cube yard per day. The effluents obtained from both filters were usually non-putrescible, though not of high quality, the deep filter effluent being rather the better of the two.

In order to improve the distribution, the filters were to some extent remodelled in the early part of 1907 ; that is to say, the distributors were levelled and the upper layers of coarse coke were replaced by finer coke ($\frac{1}{4}''$ to $\frac{3}{8}''$ diameter) to the depth of six inches on the deep filter and 3 inches on the shallow filter. Immediately below these fine layers, there were four inches in the deep filter, and two inches in the shallow filter, of medium sized coke.

From April 15th to June 28th, 1907, the filters were brought to maturity with gradually increasing quantities of septic tank liquor. During the time of the actual experiment, which lasted from June 1st, 1907 to January 20th, 1908, the quantities of septic tank liquor treated were as follows :—

On the deep filter (12′ × 9′ × 6′)—3,000 gallons, or 125 gallons per cube yard per 24 hours.

On the shallow filter (12′ × 9′ × 3′).—1,500 gallons, or 125 gallons per cube yard per 24 hours.

Between these dates, ten corresponding samples of septic tank liquor and of both filter effluents were drawn. The average figures for the analysis of the septic tank liquor were as follows :—

Septic Tank Liquor.

Parts per 100,000.

—	Maximum and minimum figures.	Average figures.	Number of estimations.
Total nitrogen	4·95 – 8·40	6·75	10
Oxygen absorbed from permanganate at once	1·17 – 4·39	3·34	10
Oxygen absorbed from permanganate in four hours	5·54 – 8·64	7·43	10
Suspended solids	5·3 – 9·2	6·9	10
Volatile matter in suspended solids	4·2 – 6·9	5·4	10

The calculated strength* of this liquor is 78·7, or after allowing for the abnormal ratio of the figure for oxygen absorbed at once to the figure for oxygen absorbed in four hours, 67·6.

The following table shows the average figures of the analysis of both effluents, with and without suspended matter :—

Effluents.

Parts per 100,000.

—	Analysis of sample containing suspended solids.		Analysis of sample after filtration through paper.	
—	Deep filter effluent.	Shallow filter effluent.	Deep filter effluent.	Shallow filter effluent.
Number of samples included in the average	10	10	7	7
Ammoniacal Nitrogen	2·92	3·55	2·93	3·54
Albuminoid Nitrogen	0·47	0·47	0·25	0·28
Total Organic Nitrogen	0·79	0·84	—	—
Nitrous Nitrogen	0·13	0·15	0·13	0·15
Nitric Nitrogen	1·94	1·35	1·94	1·35
Total Nitrogen	5·76	5·64	—	—
Oxygen absorbed at once	0·86	0·86	0·49	0·58
Oxygen absorbed in 4 hours	3·12	3·09	1·71	2·11
Incubator test (Scudder)	All passed.	8 passed, 2 failed	—	—
Incubator test (by smell)	All passed.	9 passed, 1 failed		
Dissolved Oxygen taken up in 48 hours	2·05	1·74	0·65	0·79
Dissolved Oxygen taken up in 5 days	6·62	6·49	1·49	1·90
Solids in suspension	6·40	5·10	—	—
Volatile matter in solids	4·60	3·80	—	—
Solids by Centrifuge (Vols.)	73·0	60·2	—	—

Apart from suspended solids, both effluents were of moderate quality, that from the deep filter being slightly better than that from the shallow filter as regards ammoniacal nitrogen and nitric nitrogen, the figures otherwise being very much alike.

* Strength means the number of parts by weight of oxygen required to oxidise 100,000 parts, arrived at on the basis of the formulæ suggested by Dr. McGowan—*see* p. 16 of this Report, and Dr. McGowan's Memorandum in Appendix IV.

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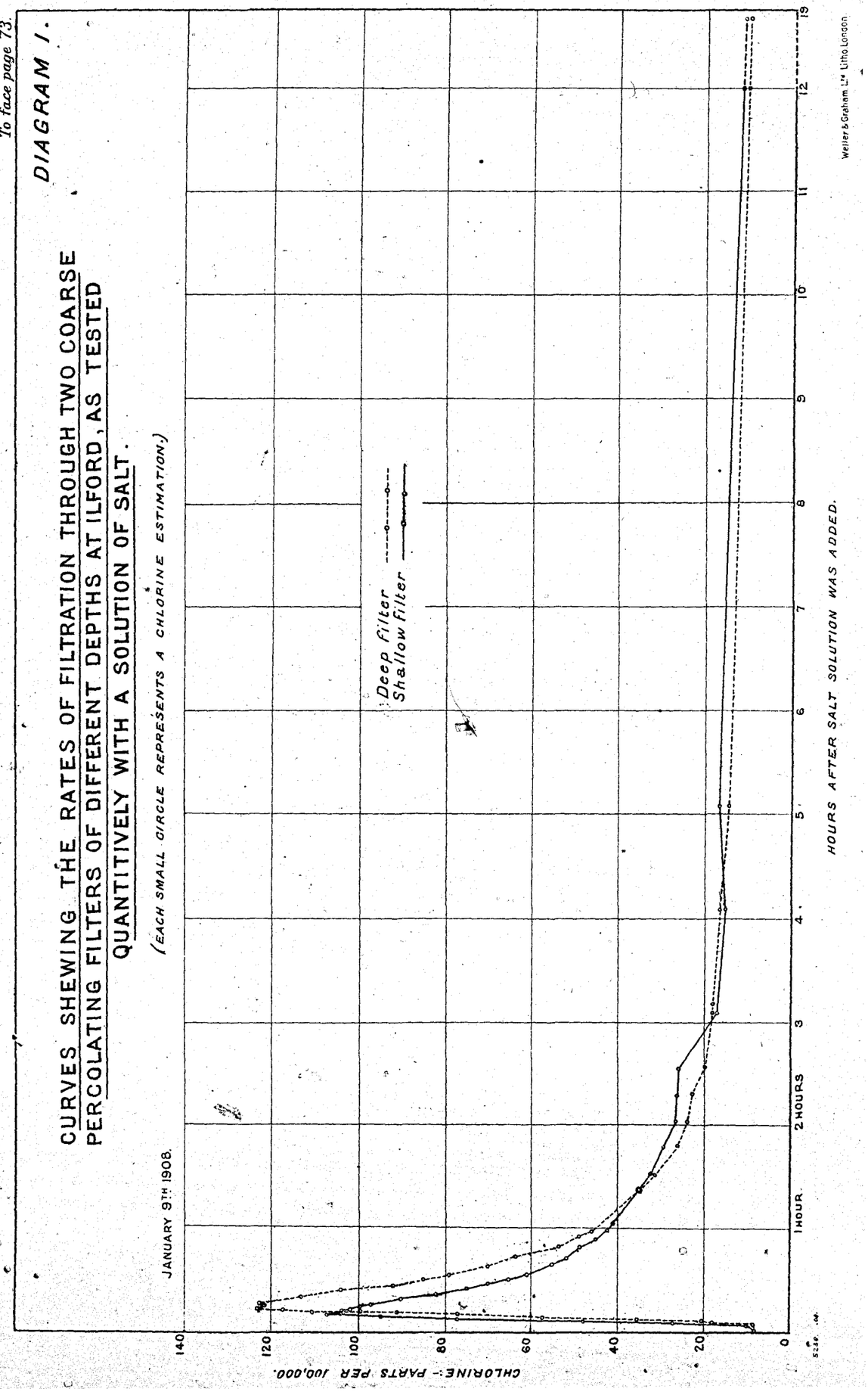

The following table showing the percentage purification obtained on the tank liquor, calculated in various ways, brings out the similarity :—

	Deep filter.	Shallow filter.
Calculated percentage purification on atmospheric oxygen used up (strength of septic tank liquor taken at 78·7). - - - -	74·6	71·8
*Units of purification on this basis (including suspended solids) -	7,339	7,063
Calculated percentage purification on atmospheric oxygen used up (strength of septic tank liquor taken at 67·6) - - - -	70·4	67·2
*Units of purification on this basis (including suspended solids) -	5,949	5,678
Calculated percentage purification, leaving out suspended solids (strength of septic tank liquor 78·7) - - - - - - -	86·3	81·4
Calculated percentage purification, leaving out suspended solids (strength of septic tank liquor 67·6) - - - - - - -	84·0	78·4

A little more work, *i.e.*, oxidation, was thus obtained from the deep filter per cube yard than from the shallow filter, but the difference was only slight, such as might be accounted for by the fact that imperfect distribution is more liable to affect the purification in a shallow filter than in a deep filter.

137. *For practical purposes we think the conclusion is justified that, within somewhat wide limits of depth, and given ample aeration and good distribution, the same amount of work can be got out of a cube yard of coarse material whether it is arranged in the form of a deep or of a shallow percolating filter.*

Rate of flow through Ilford filters.

138. With a view to ascertaining the relative rates of flow through the two filters the following experiment was made.

On January 9th, 1908, a strong solution of common salt was added to the septic tank liquor as it passed on to the two filters, samples of the effluent being taken at short intervals until almost all the salt had worked through the filters, a period in this case of about 19 hours.

The quantity of chlorine was then estimated in each sample.

It cannot be taken for granted that the passage of a solution of common salt through a filter is exactly similar to the passage of sewage impurity which is partly in true solution, partly colloidal, and partly in suspension. As sewage impurity passes through a filter it undergoes change, whereas the passage of a solution of common salt may be regarded for practical purposes as merely physical ; further, one may reasonably assume that sewage impurities are held up in the filter for a longer period of time.

The figures for the two filters were nearly alike throughout the experiment, but during the first hour a rather greater proportion of salt came through the deep filter, although, at the very beginning, the salt issued more quickly from the shallow filter. The figures are plotted out on Diagram I.

These experiments suggest that, given good distribution and ample aeration the extent of the purification effected by a percolating filter depends upon the length of time during which the liquor is in contact with the material, or, perhaps more correctly, upon the proportion of highly purified sewage in the effluent (*i.e.*, sewage which has taken hours to pass through the filter) to the proportion of sewage which has passed through more rapidly by following a much less circuitous route.

The three important factors which govern the rate of percolation are :—

(1) The kind of material, *i.e.*, whether the surface is rough or smooth ;
(2) The size of the material ; and
(3) The state of the filter as regards the bacteria and growths attached to the material, and also as regards worms, larvæ, etc.

* As to the meaning of the term "units of purification" *see* p. 107 of this Report.

Influence of the Nature of the Filtering Material.

139. We may refer to three experiments relating to the purification effected on the same sewage liquor by different filtering materials, all graded to be as nearly as possible of the same size.

In 1903, a circular filter, consisting of four kinds of material arranged in segments entirely cut off from each other by partition walls, was constructed by Mr. A. Creer at the York Sewage Works. The particulars of this filter, which was started on April 29th, 1903, were as follows :—

Diameter - - - - - -	100 feet.
Depth of material - - - -	7 feet 8 inches.

Materials.

First Segment - - - - - -	1,492 cube yards.
Clinker - - - - - -	$1\frac{1}{2}$ ins. to $3\frac{1}{2}$ ins. diameter.
Second Segment - - - - -	312 cube yards.
Broken brick - - - - -	$1\frac{1}{2}$ ins. to $3\frac{1}{2}$ ins. diameter.
Third Segment - - - - -	189 cube yards.
Blast furnace slag - - -	$1\frac{1}{2}$ ins. to $3\frac{1}{2}$ ins. diameter.
Fourth Segment - - - - -	189 cube yards.
Gas coke- - - - - -	$1\frac{1}{2}$ ins. to $3\frac{1}{2}$ ins. diameter.

The filter was fed with septic tank liquor by a continuously revolving sprinkler, working automatically, and the rate of filtration on all four sections was approximately 360 gallons per square yard, or 140 gallons per cube yard, per day.

In June, 1904, we drew hourly samples of the effluent from each of the four segments over three complete days, the twenty-four samples from each segment being in each instance made up into a single sample for each complete day. As the three twenty-four hours' samples from each segment were very near to one another in chemical composition, only the average figures for each complete set of three days need be given here :—

Parts per 100,000.	Clinker.	Coke.	Slag.	Broken brick.
Ammoniacal Nitrogen - - - - - -	0·01	0·06	0·05	0·21
Albuminoid Nitrogen - - - - - -	0·10	0·10	0·12	0·15
Oxidized Nitrogen - - - - - -	2·90	2·47	2·32	2·48
Total Nitrogen - - - - - - - -	3·18	approx. 2·95	approx. 2·72	2·88
"Oxygen absorbed" at 27°C. (80°F.) - *at once.*	0·38	0·49	0·63	0·63
" " " - *in 4 hours.*	1·46	1·27	1.48	2·23
Dissolved Oxygen taken up in 24 hours at about 18°C. - - - - - - - - -	0·09	0·19	0.24	0·37
Dissolved Oxygen, in c.c. per litre - - -	0·65	1·32	1·72	2·57
Solids in suspension - - - - - -	2 15	1·22	1·73	2·00
Solids by Centrifuge (Vols.) - - - -	33·5	24·4	20·5	30·0
Ratio of Solids in suspension to Centrifuge solids-	1 : 15·6	1 : 20·4	1 : 17·3	1 : 15·0
Incubator Test (Scudder) - - - - - -	All passed.	All passed.	All passed.	All passed.
" " (by smell) - - - - - -	All passed.	All passed.	All passed.	All passed.
Smell when analysed - - - - - -	All good.	All good.	All good.	All good.

All these effluents were very good. It will be seen, however, that if we differentiate between them, the following is the order of merit for the different materials :—

(1) Clinker.
(2) Coke.
(3) Slag.
(4) Broken brick.

Between Nos. 2 and 3, the coke and the slag filter effluents, there is really no difference.

The foregoing experiment was made between June 27th and 30th, 1904, and we thought it well to test shortly afterwards—on July 19th—the comparative rates at which liquid coloured by fluorescine came through the different segments. The filtrates showed :—

———	(*a*) Weak colour.	(*b*) Strong colour.
	Minutes.	Minutes.
1. Clinker - - - - - - - - - - - -	6	12
2. Coke - - - - - - - - - - - -	5	8
3. Slag* - - - - - - - - - - - -	8	9
4. Broken brick - - - - - - - - - -	2	$2\frac{1}{2}$

The order of the rate of percolation, as measured in this way, was thus the same as that of the purity of the effluent. Although the different filtering materials were all broken to be of the same size, the clinker was in reality somewhat smaller than the other three.

These experiments tend to confirm the view that the extent of the purification effected by a percolating filter depends upon the length of time taken by the sewage to pass through the filtering material, assuming always that the filter is properly aerated. Having regard to the vesicular nature of the clinker we should expect it to retard the passage of the sewage more than the broken brick, and hence to give a better effluent. The analytical results show that this was the case.

In his experiments at Hendon upon the filtration of crude sewage through medium-sized material, the late Colonel Ducat compared the results obtained from filters constructed of small pebbles and of clinker, both material being of the same size. The length of time taken by the sewage in passing through the clinker was, no doubt, greater than that taken by its passage through the pebbles, and the analytical results showed that better purification was obtained from the filter which was made of clinker.

In a laboratory experiment which was made by us at Leeds in the year 1900, we found that, using large smooth water-washed stones as the material in a filter five feet deep and one foot in diameter, and treating Leeds septic tank liquor at an approximate rate of about 70 gallons per cube yard per day, only traces of oxidised nitrogen appeared in the effluent after three or four months' working: Nitric nitrogen appeared in the effluents from the Whittaker filters at Leeds in a much shorter time than this. These latter filters were constructed of coarse coke or clinker and were fed with septic tank liquor at about the same rate, *i.e.*, 70 gallons per cube yard per day.

140. The results of these experiments may be summarised as follows :—

(1) Better results can be obtained per unit volume from a material with a rough surface than from a material with a smooth surface ; and

(2) The extent of the purification effected by a percolating filter varies with the average length of time taken by the sewage to pass through the filtering material, assuming that proper aeration of the filter is maintained.

Influence of the Size of the Material.

141. Although the experiments which we carried out at Ilford and Horfield showed that, with filters of coarse material, and given good distribution and ample aeration, a cube yard of filtering material will produce very similar results whether it is arranged in the form of a deep or of a shallow filter, it does not follow that this conclusion would apply to filters of medium-sized and fine material.

There are in reality three distinct classes of percolating filter in use for the purification of sewage or sewage liquors, viz. :—

(1) Percolating filters constructed of material coarse enough (say, over $2\frac{1}{2}''$ in diameter) not only to give free access of air to its interior but also to allow the suspended matter in the liquid free passage through the whole depth of the filter. This is the class of filter to which the Ilford and Horfield experiments related.

* The amount of effluent coming from the slag segment was very small, owing to a strong wind on that side of the filter. The result for this section may therefore be of less value than would otherwise have been the case.

(2) Percolating filters constructed of medium-sized material (say, ½″ in diameter), which temporarily retards the passage of suspended matter through the filter, while allowing free access of air to the interior.

(3) Percolating filters constructed of very fine material.

Percolating Filters Constructed of Medium-Sized Material.

142. In filters constructed of medium-sized material the suspended solids are arrested and held for some time in the upper layers of the material, and this part of the filter therefore receives a larger proportion of oxidizable suspended matter than the middle or lower parts. Where much suspended matter has to be dealt with, such filters tend to become choked in the uppermost few inches of the material, and to prevent the proper distribution of the liquid over the bed. In a filter of this kind, air is probably carried into the interior from the top downwards by the fall of the sewage liquor upon the material. There are many examples of filters of this class where the material is held in position by solid walls and where air could only gain access to the filter either through the outlet valves connecting to the drains or through the surface of the material. Colonel Harding and Mr. Harrison, at Leeds, showed clearly that after serious ponding took place on the surface of a filter of medium-sized material, although provided with perforated walls which would allow of side aeration, oxidized nitrogen almost entirely disappeared from the effluent, and the effluent then became putrescible. This experiment, however, does not conclusively show that aeration does not also take place through the sides of a filter with perforated walls, as the deterioration of the effluent might have been due to the unequal passage of the sewage liquor through the bed owing to impaired distribution, and so far as we are aware no experiments have been made which show conclusively how the interior of a percolating filter of medium-sized material is replenished with air.

On general grounds, we should think it better to arrange a given volume of medium-sized material in the form of a shallow rather than of a deep percolating filter. In this way better aeration would be maintained throughout the filter and the suspended solids in the liquor treated would be spread over a greater quantity of the filtering material.

Percolating Filters Constructed of Very Fine Material.

143. In filters constructed of very fine material, the material not only retains suspended matter on the surface, but also prevents the free access of air to the interior. When sewage liquor is applied to such a filter, almost the whole of the suspended matter is retained on the surface of the material, with the result that after a time the surface becomes completely choked. The filter has then either to be washed by upward flow, with simultaneous raking of the top few inches of the fine material, or it must be rested until the suspended matter on the surface is sufficiently dry to be raked off.

In the majority of cases, these filters are fed from a flushing tank, or the fine material itself is wholly relied upon for aiding uniform distribution. As showing that in the latter case (and presumably in the former also) a filter depends chiefly upon periods of rest for the access of air to the interior, we may quote the following experiment :—

At Prestolee, in Lancashire, there are three small filters which have a surface layer of very fine clinker: the material at the bottom of the filter is about one inch in diameter. The filters are entirely closed in at the sides, and at the bottom connect with the air through a single outlet valve only. The method of working the filters is simply to allow the septic tank liquor to flow on to the surface of one of them by means of half pipes, and then to percolate through to the outlet drains. The suspended matter in the tank liquor, being caught on the surface, soon chokes the fine material near the half pipes, and the liquor then gradually spreads over the whole surface of the filter. When the surface is about two-thirds or four-fifths ponded, the tank liquor is diverted to the second filter and the first is allowed to rest and dry off, after which the suspended matter is carefully removed with a spade.

144. In order to gain some idea as to how long it would be possible to work one of these filters without resting, the following experiments were made :—

On Wednesday, January 4th, 1905, at 2.30 p.m., septic tank liquor was turned on to Bed No. 1, which had previously been rested for 29½ hours, *i.e.*, a shorter period of

rest than the usual two days. The first samples of effluent from the bed were drawn thirty minutes after the start, at which time the effluent had begun to flow out at a fair rate, and others were taken out from time to time, as shown in the table below. The experiment lasted until January 9th, at 4.20 p.m., *i.e.*, for fully five days, the weather for the greater part of this time being showery, but the flow of sewage never much above the normal.

During the course of the experiment, four samples of septic tank liquor were drawn, viz :—

On January 4th at 2.30 p.m.
On January 5th at 10.45 a.m.
On January 6th at 9.45 a.m.
On January 9th at 4.0 p.m.

These samples were very much alike in composition, and the figures of analysis are therefore averaged in the table, and placed in one column. Incidentally they show that the liquor is very weak, but this is quite normal for Prestolee.

—	Average of 4 Septic Tank Liquors.	Effluents.					
Drawn	- -	Jan. 4th., 30 minutes after starting filter.	Jan. 4th, 6½ hours after starting filter, the surface of which was then three quarters ponded.	Jan. 5th., 20¾ hours after starting filter, the surface of which was then four-fifths ponded.	Jan. 5th., 27½ hours after starting. Surface almost completely ponded	Jan. 6th., 43¾ hours after starting. Surface nine-tenths ponded.	Jan. 9th., 121½ hrs. after starting. Filter surface then completely ponded.
Analysed :	- -	Jan. 5th.	Jan. 6th.	Jan. 6th.	Jan. 9th.	Jan. 9th.	Jan. 10th.
Parts per 100,000.							
Ammoniacal Nitrogen * -	0·75 (4) *	0·04	0·19	0·28	0·26	0·32	0·60
Albuminoid Nitrogen -	0·22 (4)	0·07	0·06	0·05	0·07	0·07	0·07
Oxidized Nitrogen -	—	0·90	0·44	0·40	0·32	0·27	0·00
"Oxygen absorbed" *at once* at 27°C - -	0·76 (4)	0·14	0·23	0·17	0·29	0·35	0·31
"Oxygen absorbed" *in 4 hours* - - - -	3·21 (4)	0·56	0 91	0·47	0·77	0·81	0·65
Dissolved oxygen taken up in 24 hours at 18°C -	1·20 (1)	0·48	0·62	0·85	0·56	0·66	0·55
Incubator test (Scudder) -	—	Passed.	Passed.	Passed.	Passed.	Passed.	Failed.
„ „ (by smell) -	—	Passed.	Passed.	Passed.	Passed.	Passed.	Failed.
Smell when drawn - -	—	Faint soapy.	Good.	Good.	Good.	Good.	Strong sewage.
Smell when analysed -	—	Slight soapy and earthy.	Slight soapy.	Good.	Slight soapy and earthy.	Good.	Slightly unpleasant.
Chlorine - - -	2·93 (4)	—	—	—	—	—	—
Solids in suspension -	6·42 (2)	—	—	—	—	—	—
Solids by centrifuge (vols.)	17·4 (3)	0·0	0·0	0·0	0·0	0·0	0·0
Oxygen in solution (when analysed) - - - *c.c. per litre* †	—	5·6	4·2	5·1	0·0	1·0	0·7

* The figures in brackets indicate the number of estimations in each case.

† In comparing the figures for dissolved oxygen found on the day of analysis, it is important to note that these estimations were made at different intervals of time after the samples were drawn. Those which could not be examined at once were kept in ice, but the second sample of January 5th was at atmospheric temperature for two days after being drawn; this no doubt accounts for its oxygen being exhausted.

At 6½ hours after the start, the bed had become ponded over three-fourths of its surface and the ponding gradually increased, but with fluctuations, until the bed was completely under water.

Concurrently with this, the figures for ammoniacal nitrogen and for nitric nitrogen (no nitrite being present in any sample on the day of analysis) show that the oxidation gradually decreased as the experiment proceeded. The figures both for "oxygen absorbed" from permanganate and for dissolved oxygen absorption are less regular, but this is no doubt partly due to the fact that all the effluents could not be examined at equal intervals of time after they were drawn. After five days the effluent even from this very weak tank liquor became putrescible.

145. It is clear, therefore, that percolating filters of very fine material can only be worked for a certain limited time without being rested, and, in order to obtain the maximum amount of work out of a given quantity of fine material, it would seem better to arrange it in the form of a shallow rather than in the form of a deep filter, provided the distribution is efficient.

Depth of Fine Percolating Filters.

Reid, 27075–27164.

146. The question of the most suitable depth for fine filters was specially brought to our notice by Dr. George Reid, the Medical Officer of Health for the County of Staffordshire.

In connection with his investigation of the fine grain filters at Hanley, Dr. Reid collected samples at the following depths from the surface of the filters, viz. :—1 foot, 2 feet, 3 feet, and (the bottom) 4 feet 6 inches.

The analyses of these samples, and also of the septic tank liquor, the detritus tank liquor, and the original sewage, are given in the following table :—

Parts per 100,000.

——	Sewage.	Detritus Tank.	Septic Tank.	Filter 1 foot	Filter 2 feet	Filter 3 feet	Filter 4·5 feet
No. of Records	18	13	16	16	16	16	16
Total Solids	170·9	118·1	107.8	101·5	101·1	101·8	103·5
Solids in Suspension	63·5	17·0	7·6	0·25	0·09	0·14	—
Solids in Suspension (Organic)	28·5	6·8	3.8	0·16	0·05	0·06	—
Solids in Suspension (Mineral)	34·9	10·1	3·8	0·08	0·03	0·08	—
Chlorine	11·0	10·0	9·9	9·4	9·5	9·4	9·5
Free Ammonia	2·154	1·643	1·716	0·036	0·020	0·009	0·043
Albuminoid Ammonia	0·972	0·486	0·340	0·052	0·037	0·031	0·027
*Oxygen absorbed in 4 hours at 80°F.	5·019	2·726	2·184	0·328	0·286	0·244	0·259
*Oxygen absorbed in 3 minutes before incubation	1·862	0·975	0·836	0·093	0·077	0·060	0·070
Oxygen absorbed in 3 minutes after incubation (3 days)	2·176	1·095	1·571	0·0677	0·060	0·052	0·039
Nitric Nitrogen on day of collection	0·02	0·02	Nil	1·64	1·82	1.75	1·70
Nitric Nitrogen day after collection	0·10	0·09	0·09	2·07	1·99	1·85	1·99
Nitrous Nitrogen on day of collection	0·029	0·014	Nil	0·003	0·011	0·005	0·005
Nitrous Nitrogen day after collection	0·029	0·022	Nil	0·003	0·007	0·008	0·002
Column necessary to obscure test lines (inches)	0·5	1·6	1·5	Over 24	Over 24	Over 24	Over 24

From these experiments Dr. Reid had drawn the inference that, in the case of the Hanley sewage "the lower two or three feet of filter medium is absolutely unnecessary, and so far as the cost of construction of the filters is concerned, the expenditure might be reduced by about one-half."

* From weak permanganate.

He also suggested that a much better result would be obtained from a given quantity of *fine* filtering material if it were arranged in the form of a shallow filter, than if it were arranged in the form of a filter 6 feet deep; and, further, that to estimate the amount of filter required for a given flow of sewage, in cubic yards, without reference to the depth of the filter, was open to objection, inasmuch as the lower layers of a fine filter were less efficient than the top one or two feet. Reid, 27145.

The points raised by Dr. Reid are of considerable importance, and we considered it desirable to make further experimental investigations in regard to them, especially as the results obtained at Hanley in respect of fine filters differed so materially from the results which we had obtained elsewhere with coarse filters.

Dorking experiments as to depth of filters.

147. Our experiments were carried out at Dorking, under the charge of Mr. E. H. Richards, our resident chemist. For the purpose of the experiments, we constructed two filters 4 feet 10 inches deep, one filled with fine material and the other with coarse material, and two filters 2 feet 5 inches deep, one filled with fine material and the other with coarse material.

For convenience the two deep filters were constructed in the form of one circular filter with a dividing partition between the coarse and fine material. The shallow filters were also constructed in a similar manner. The distribution was by means of revolving sprinklers, fed intermittently from small tipping troughs. At the suggestion of Dr. Reid, who very kindly gave every possible help in the planning of the experiment, the distribution was carefully tested before the experiment started and was found to be as perfect as could reasonably be expected. The flush of tank liquor (5 gallons) on to the filters took place as follows :—

During Experiment I. - - once every 7 minutes.

During Experiment II. - - once every 3½ minutes.

The following table gives particulars of the four filters :—

Dorking Experimental Filters.

——	Material.	Depth of Material.	Size of Material.	Contents of filter.
				Cube yards.
Coarse Shallow Filter	Clinker.	2′ 5″	1″ to 4″ throughout.	5·14
Coarse Deep Filter	Clinker.	4′ 10″	1″ to 4″ throughout.	10·28
Fine Shallow Filter	Clinker.	2′ 5″	Top 1′ 2½″ of ⅛″ to ¼″ diam. Bottom 1′ 2½″ of ¼″ to ½″ diam.	5·14
Fine Deep Filter	Clinker.	4′ 10″	Top 2′ 5″ of ⅛″ to ¼″ diam. Bottom 2′ 5″ of ¼″ to ½″ diam.	10·28

The sewage treated in the experiments was drawn, by means of a bypass, from the Dorking outfall at a constant flow. It may be described as almost entirely domestic sewage of about average strength.

Table I. shows the figures of analysis given by 21 sets of average samples of the sewage taken from November, 1905, to November, 1906.

TABLE I.

Figures for Screened Sewage.

24-hours samples.

Parts per 100,000.	Average.	No. of estimations.
Ammoniacal Nitrogen (2·63 to 5·69)	4·65	21
Albuminoid Nitrogen (0·56 to 1·66)	1·00	20
Total Organic Nitrogen (1 17 to 3 11)	1·92	20
Oxidized Nitrogen (0·00 to 0 76)	0·11	21
Total Nitrogen (4·51 to 5·88)	6·72	20
Oxygen absorbed at once at 27°C. (1·20 to 3·41)	2·38	21
Oxygen absorbed in 4 hours (6 37 to 14·77)	10·01	21
Solids in suspension (11·7 to 32·8)	21·50	21
Calculated strength* 96	—	—

* Strength expressed in terms of the number of parts by weight of oxygen required to oxidize 100,000 parts of sewage, arrived at on the basis of the formulæ suggested by Dr. McGowan—*see* p. 16 of this Report, and Dr. McGowan's Memorandum in Appendix IV.

The sewage, before filtration, was precipitated with ten grains of alumino-ferric and five grains of lime per gallon, and was then allowed to pass through a tank of sufficient capacity to give ten hours continuous flow settlement. The tank was cleaned once a week, as a rule, but twice a week in hot weather.

Experiment I. (*June* 17*th*, 1907, *to October* 17*th*, 1907.)

148. On June 17th, 1907, the four filters were started working at the rate of seventy-five gallons per *square yard* per day for each filter. This was equivalent to a rate of ninety-three gallons per cube yard for each shallow filter and 46·5 gallons for each deep filter. This small dose was intentional, the idea being to work the filters with gradually increasing volumes of liquor and to note the order in which the effluents deteriorated in quality. The above rate of working continued without cessation until October 17th, 1907. The surface material of the coarse filters was soon covered with a green growth as is usual at Dorking at that time of the year. The growth was thin and had no apparent effect upon the aeration of the filters or upon the passage of the tank liquor through the material.

The material in the two fine filters was comparatively free from growth, and at no time during this experiment did any ponding of the surface occur. The upper layers of the fine material swarmed with small red worms.

During the four months all the effluents and the precipitation liquor were examined by sets of average samples drawn hourly for eight hours every eight days.

The figures given in Table II. are therefore representative of the working of the filters under all conditions.

TABLE II.

Deep and Shallow Filter experiment.

Average Figures of Analysis for Precipitation Liquor and Effluents.

All Filters working at the rate of 75 gallons per square yard.

Twelve Analyses.

June 27th to September 27th, 1907.	Ammoniacal Nitrogen.	Albuminoid Nitrogen.	Nitrous Nitrogen.	Nitric Nitrogen.	Oxygen absorbed in 3 minutes at 27° C.	Oxygen absorbed in 4 hours at 27° C.	Dissolved oxygen taken up in 48 hours at 18° C.	Dissolved oxygen taken up in 5 days at 18° C.	Incubator test (Smell).	Solids in Suspension.	Centrifuge (Volumes).	Chlorine.	Rate of Filtration in Galls. per cube yard.
Precipitation liquor	4·94	0·51	0·02	0·08	1·72	5·44	—	—	—	5·73, 3·53 (vol.) 2·20 (non-vol.)	60	—	—
Coarse shallow filter effluent	0·66	0·11	0·14	3·14	0·47	1·35 1·12 (paper filtered)	0·57	1·47 0·48 (paper filtered)	12+	1·53, 0·99 (vol.) 0·54 (non-vol.)	27	—	93
Coarse deep filter effluent	0·14	0·08	0·05	4·03	0·31	0·91 0·76 (paper filtered)	0·24	0·67 0·32 (paper filtered)	12+	1·28, 0·77 (vol.) 0·51 (non-vol.)	26	—	46·5
Fine shallow filter effluent	0·08	0·04	0·04	4·00	0·27	0·57	0·04	0·12	12+	—	None	—	93
Fine deep filter effluent	0·03	0·04	Trace.	4·26	0·16	0·51	0·03	0·15	12+	—	Trace	—	46·5

The sign + means that the sample did not putrefy on incubation.

The precipitation liquor treated was fairly strong. It had a calculated strength * of about sixty-one.

The effluents from the two coarse filters were both very good, but the *liquid* portion of effluent from the deep filter contained only about two-thirds as much oxidizable matter as that from the shallow filter, as judged by the oxygen absorbed test. The difference is shewn by the following figures :—

—	Effluent from the coarse shallow filter.	Effluent from the coarse deep filter.
Ammoniacal nitrogen	0·66	0·14
Nitric nitrogen	3·14	4·03
Oxygen absorbed in 4 hours by paper-filtered effluent	1·12	0·76
Dissolved oxygen taken up in 5 days by paper-filtered effluent	0·48	0·32

The effluents from the two fine filters were, for practical purposes, alike, the oxidation having been carried very far in each case, as is shown by the following figures :—

—	Effluent from fine shallow filter.	Effluent from fine deep filter.
Ammoniacal nitrogen	0·08	0·03
Nitric nitrogen	4·00	4·26
Oxygen absorbed from permanganate in 4 hours	0·57	0·51
Dissolved oxygen taken up in five days	0·12	0·15

All four effluents may be classed as good to very good, and all the filters were sufficiently, or more than sufficiently, deep, for the volume and the strength of the liquid treated.

The results from the deep and shallow fine filters are in agreement with those obtained by Dr. Reid at Hanley. They show that, *with the amount of sewage liquor being treated,* the extra depth in the deep filter was not required ; or, in other words, that passage through the first half of the deep filter was sufficient to oxidize almost the whole of the oxidizable matter in the liquor put on the filter.

Salt Experiment I.

149. At the conclusion of this first experiment an attempt was made, as at Ilford, to find the approximate average time taken by the precipitation liquor to pass through each filter.

About 28 lbs. of common salt were dissolved in water, and half the solution was poured into the tipping-trough supplying each pair of filters, in such a way as to interfere as little as possible with the natural working of the distributors.

Approximately 7 lbs of salt were thus flushed on to each filter.

Samples of the four effluents were taken first at one minute intervals, and subsequently at longer intervals over a period of 56 hours, until the salt had apparently all passed through the filters.

The chlorine in these samples plotted against time of drawing is shewn in Diagram 2.

These curves suggest the conclusion that a sample of effluent drawn at a given time is composed of a mixture of liquid which has been in contact with the filtering material for times varying (in all four cases) from about thirty minutes or less, to something like sixty *hours* or more.

The proportion of liquid which has been in contact with the filtering material for a short time to the proportion of liquid which has been in contact for a long time would largely depend upon the depth of the filter, and upon the nature and size of the material of which the filter is composed.

* *See* section of this Report on Strength of Sewage, p. 15.

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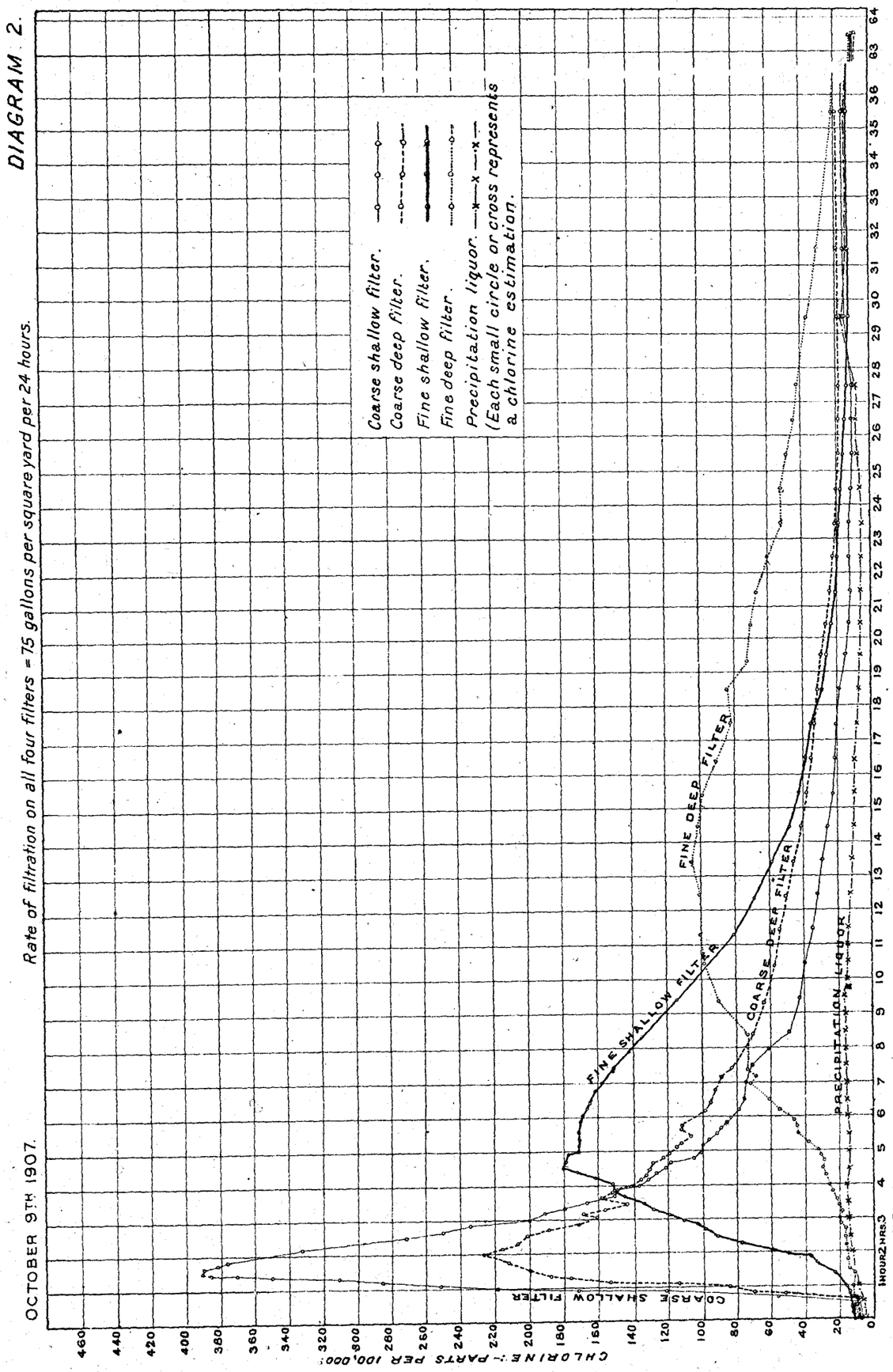
CURVES SHEWING THE RATES OF FILTRATION THROUGH THE TWO COARSE AND THE TWO FINE FILTERS AT DORKING, AS TESTED QUANTITIVELY, WITH A SOLUTION OF SALT.

DIAGRAM 2.



To draw any exact conclusions as to the average time of contact in each of the four filters appears to be almost impossible. We may, however, give the following ratios, etc :—

—	Total quantity of salt washed out of filter in 30 hours.		Time taken for half the average quantity of salt to wash out.		Hour line upon which the centre of gravity of the curve figure falls.		Total area enclosed by the curve figure.	
	Weight in lbs.	Proportion to 7 lbs	Hours.	Time ratio.	Hours	Hour line ratio.	Cubic inches.	Area ratio.
Coarse shallow filter - -	4·36	0·62	3·0	1 0	5·33	1·00	12·9	1.00
Coarse deep filter - -	4·59	0·65	5·5	1·8	9·0	1·63	13·0	1·01
Fine shallow filter - -	4·98	0·71	7·0	2·3	9·0	1·63	14·0	1·08
Fine deep filter - - -	5·42 (39 hrs.)	0·77	14·5	4.8	17·0	3·10	14·0	1·08
Average - - - -	4·83	—	—	—	—	Average.	13·5	—

As judged by the time taken for half the average weight $\left(\frac{4{\cdot}83}{2}\text{lbs.}\right)$ of salt to issue in the effluent, the time of contact in the coarse deep filter was nearly double that given in the coarse shallow filter, and rather less than the time of contact given in the fine shallow filter. In the fine deep filter it was almost exactly double the time given in the fine shallow filter.

Upon this basis of calculation, the fine deep filter ought to give the best effluent, the fine shallow filter the next, the coarse deep filter the next, and the coarse shallow the worst. The quantities of oxidizable matter treated were not sufficient to give any true idea of the relative oxidizing power of each filter, but it will be seen that the figures of analysis do arrange the effluents in this order.

Experiment II. (*October* 18*th*, 1907, *to January* 12*th*, 1908.)

150. On October 18th, 1907, the rate of working was increased to 150 gallons per *square yard* per day for each filter. This was equivalent to a rate of 186 gallons per cube yard for each of the two shallow filters and 93 gallons for each of the two deep filters. This rate of working continued until December 22nd, when all the filters were given a week's rest in cold dry weather. On December 29th they were started again at the same rate, and from this time they worked without cessation until January 28th, when the experiment stopped.

The increased rate of working and the low atmospheric temperature showed their effects on the nitrification, the ammonia rising and the nitrate falling in all the effluents. Moreover, a grey growth (*Cladothrix dichotoma*, Cohn) made its appearance and began to flourish on the surface of the two coarse filters towards the end of October, gradually increasing in thickness during the two following months.

The same growth appeared on the surface of the two fine filters; this also increased, but never to anything like the same extent as on the coarse filters. On November 20th local ponding began on both fine filters, being rather worse on the shallow filter than on the deep. On December 2nd both the fine filters were raked over for the first time, and as this was done afterwards whenever necessary, neither the growth nor the suspended matter caught in the top few inches of the fine clinker had very much effect upon the working of these filters. There is no doubt that the effect of the growth was much more marked in the case of the two coarse filters.

The severe frosts in January killed off the growths on the fine filters, and to a certain extent on the coarse filters also, but with the return of the milder weather the growth re-asserted itself. Although the filters were at times completely frozen over between the jets of the sprinklers, none of the effluents deteriorated seriously. The coarse deep filter suffered most in this way from its exposed position.

The averages of the figures of analysis are given in Table III.

They were obtained from samples drawn in an exactly similar way to those in Experiment I.

TABLE III.

Deep and Shallow Filter Experiment.

Average Figures of Analysis for Precipitation Liquor and Effluents.

All Filters working at the rate of 150 gallons per square yard.

Ten Analyses.

October 22nd, 1907, to January 12th, 1908.	Ammoniacal Nitrogen.	Albuminoid Nitrogen.	Nitrous Nitrogen.	Nitric Nitrogen.	Oxygen absorbed in 3 minutes at 27° C.	Oxygen absorbed in 4 hours at 27° C.	Dissolved Oxygen taken up in 48 hours at 18° C.	Dissolved Oxygen taken up in 5 days at 18° C.	Incubator test (smell)	Solids in Suspension.	Centrifuge (volumes).	Chlorine.	Rate of filtration in gallons per cube yard per day.
Precipitation Liquor - -	4·13	0·50	0·09	0·19	1·44	4·85	—	—	—	5·70, 3·03 (vol.) 2·67 (non-vol.)	64	7·48	—
Coarse shallow filter effluent - -	0·99	0·16	0·08	2·23	0·41	1·26 0·87 (paper filtered)	1·00	2·42 0·52 (paper filtered)	10+	2·65, 1·75 (vol.) 0·85 (non-vol.)	53	7·05	186
Coarse deep filter effluent -	0·55	0·10	0·07	2·69	0·27	0·94 0·79 (paper filtered)	0·51	1·40 0·42 (paper filtered)	10+	1·51, 1·09 (vol.) 0·42 (non-vol.)	34	7·07	93
Fine shallow filter effluent -	0·86	0·11	0·05	2·80	0·34	0·90	0·46	1·03	10+	1·00 (approx.)	26	7·02	186
Fine deep filter effluent - -	0·35	0·06	0·03	3·25	0·24	0·60	0·21	0·42	10+	0·25 (approx.)	5	7·02	93

In this second experiment, the precipitation liquor treated was distinctly weaker than it was in the first experiment. Its calculated strength was only fifty-four as against sixty-one. This was no doubt owing to the heavy rainfall in the last months of the year.

Comparing the effluents from the the two coarse filters, we have the following figures :—

	Effluent from the coarse shallow filter.	Effluent from the coarse deep filter.
Ammoniacal Nitrogen - - - - - - - - - - -	0·99	0·55
Nitric Nitrogen - - - - - - - - - - -	2·23	2·69
Oxygen absorbed in 4 hours by paper-filtered effluent - - -	0·87	0·79
Dissolved Oxygen taken up by paper-filtered effluent in 5 days - -	0·52	0·42

It would have been expected that with the greater flow per cube yard the difference between the effluents from the two coarse filters would have become accentuated, but in actual fact it is, if anything, rather less than it was in Experiment I, though at the same time neither effluent was of quite such good quality. The explanation of this result is, we think, to be found in the development of growths upon the surface of the coarse material and some way down into it which took place during the experiment. This undoubtedly interfered with the normal working and, as will be shown later, altered the times of contact given. With regard to the effluents from the fine filters (which, it will be remembered, were in the first experiment practically identical), these showed a greater difference than before as is evident from the following figures :—

	Effluent from fine shallow filter.	Effluent from fine deep filter.
Ammoniacal Nitrogen - - - - - - - - - - -	0·86	0·35
Nitric Nitrogen - - - - - - - - - - -	2·80	3·25
Oxygen absorbed in 4 hours by paper-filtered effluent - - -	0·90	0·60
Dissolved Oxygen taken up in 5 days - - - - - - -	1·08	0·42

Some growth occurred on the fine filters, but it had much less effect upon the working of them than the growth had upon the working of the coarse filters, mainly because of the surface raking adopted.

So far as the coarse filters in Experiment II are concerned, the value of the comparison of the results was vitiated by the growth.

As regards the fine filter effluents, while both are good, that from the deep filter contained only about half the residual oxidizable matter as that from the shallow filter.

At the same time, the total amount of matter which was oxidized by the fine filter, 4 feet 10 inches deep, was little more than the total amount which was oxidized by the fine filter of half the depth.

As in Experiment I., all the filters continued sufficiently (or more than sufficiently) deep for the volume and strength of the liquor treated.

Salt Experiment 2.

151. At the conclusion of Experiment II another salt test was made in order to compare the curves obtained at this rate of flow (150 gallons per square yard) with those in Experiment I when the rate was 75 gallons per square yard.

The result is shewn in Diagram 3. Exactly the same amount of salt was used as before, viz. 7lbs. for each of the four filters, but as the flow of liquid was now doubled, the chlorine figures are correspondingly lower in each case.

Interpreting the curves in the same way as those of Diagram 2, we obtain the following figures :—

—	Total quantity of salt washed out of filter in 23 hours.		Time taken for half the average quantity of salt to wash out.		Hour line upon which the centre of gravity of the curve figure falls.		Total area enclosed by the curve figure.	
	Weight in lbs.	Proportion to 7 lbs.	Hours.	Time ratio.	Hours.	Hour line ratio.	Cubic inches.	Area ratio.
Coarse shallow filter	4·2	0·60	2·27	1·00	3·8	1·00	6·98	1·00
Coarse deep filter	4·87	0·69	3·00	1·32	5·6	1·48	7·96	1·14
Fine shallow filter	4·17	0·60	3·70	1·63	5·8	1·53	6·28	0·90
Fine deep filter	4·36	0·62	6·30	2·77	9·4	2·48	6·98	1·00
Average	4·40	—	—	—	—	Average.	7·05	—

It will now be seen that in the two coarse filters, especially in the shallow one, the time taken for half the average quantity of salt to wash out was distinctly more than half what it was in Experiment I.

The effect of this is to bring the ratio figures for average time of contact in the two coarse filters much nearer together, viz., 1·0 : 1·32 as against 1·0 : 1·8 in Experiment I.

The same thing is seen but to a lesser extent with the fine filters, where the ratio figures are 1·63 : 2·77 as against 2·3 : 4·8.

The figures of analysis run parallel with this, there being less difference between the two coarse filter effluents than in Experiment I. Further, the rate of filtration is now sufficient to bring about a difference in the figures of analysis for the fine filter effluents.

Salt Experiment 3.

152. The appearance of the filters at this time led us to surmise that the difference between the ratio figures of Salt Experiment 1 and those of Salt Experiment 2 was to be ascribed to the development of *Cladothrix dichotoma* on the filtering material, especially on the coarse material.

In order to satisfy ourselves as to this, we cut down the flow on to the filters to the original rate of 75 gallons per square yard *immediately* after the conclusion of Salt Experiment 2, and proceeded to make a third Salt Experiment. Apart, therefore, from the difference in the state of the filters, the conditions of this Experiment were precisely the same as in Salt Experiment I.

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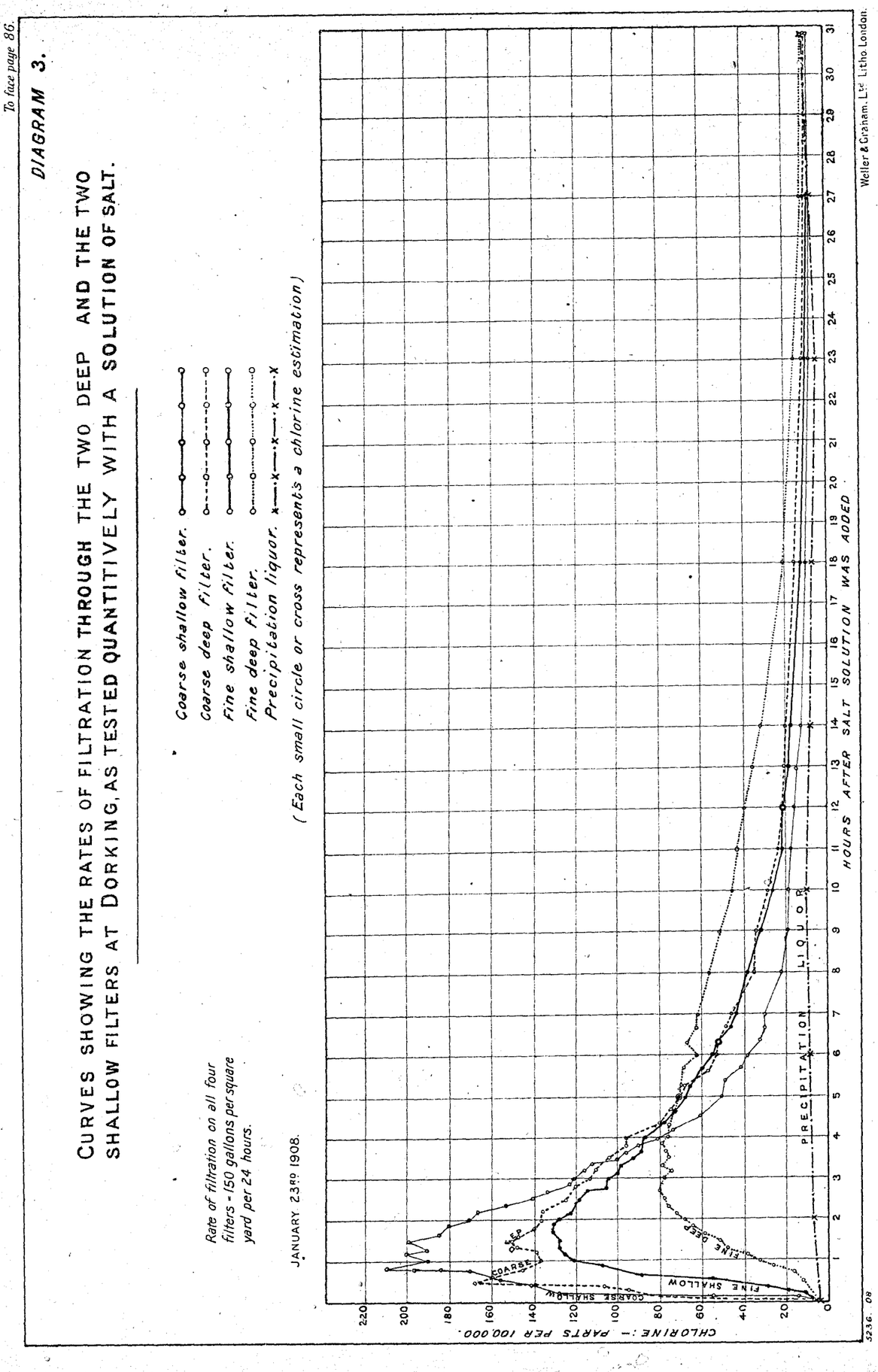

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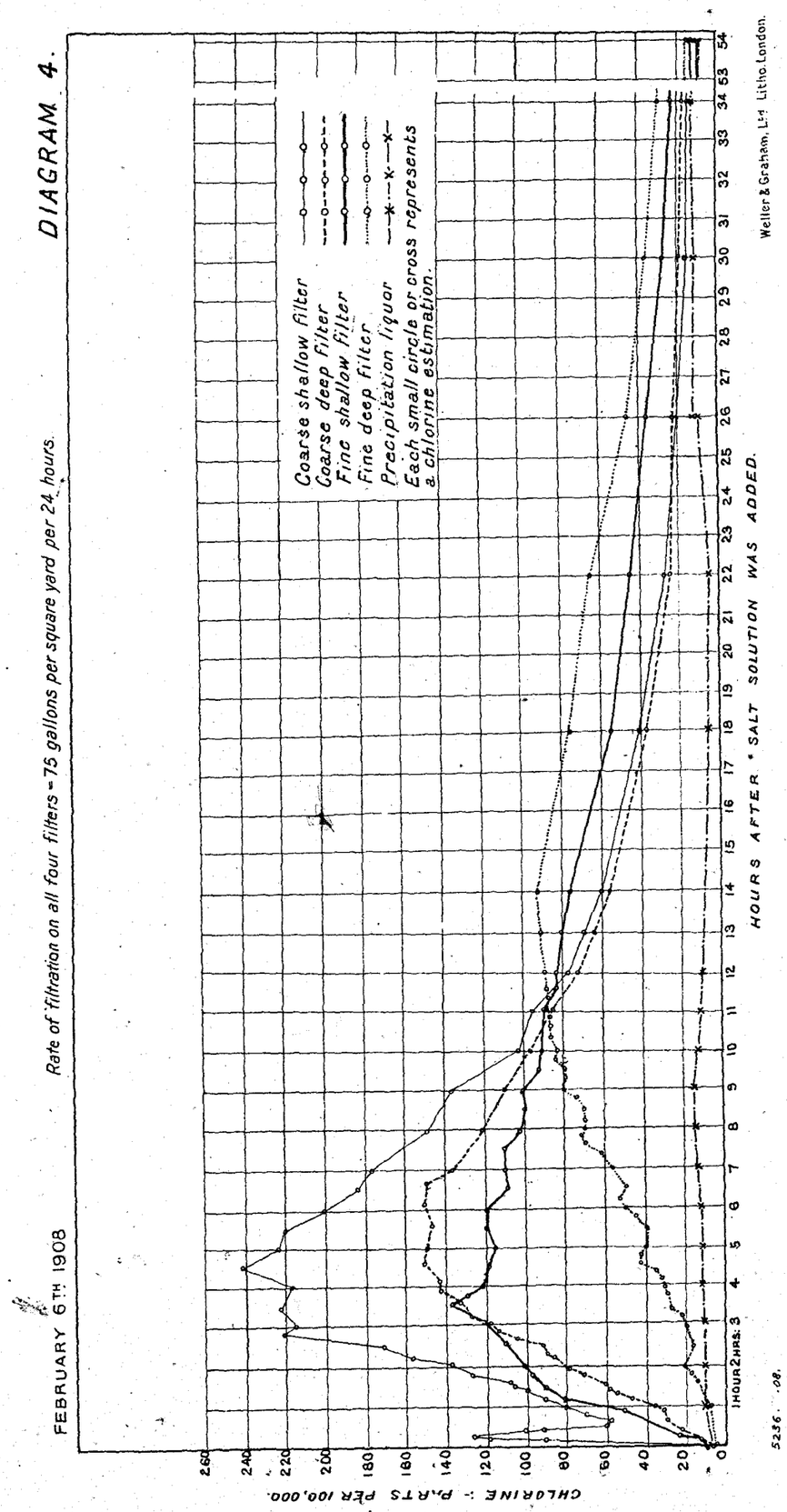
CURVES SHEWING THE RATES OF FILTRATION THROUGH THE TWO COARSE AND THE TWO FINE FILTERS AT DORKING, AS TESTED QUANTITIVELY WITH A SOLUTION OF SALT.



The result of Salt Experiment 3 is shewn on Diagram 4.

Again interpreting the curves as before we obtain the following figures :—

—	Total quantity of salt washed out of filter in 46 hours.		Time taken for half the average quantity of salt to wash out.		Hour line upon which the centre of gravity of the curve figure falls.		Total area enclosed by the curve figure.	
	Weight in lbs.	Proportion to 7 lbs.	Hours.	Time ratio.	Hours.	Hour line ratio.	Cubic inches.	Area ratio.
Coarse shallow filter - -	6·97	0·99	6·3	1·00	8·8	1·00	22·26	1·00
Coarse deep filter - -	6·02	0·86	9·1	1·44	11·0	1·25	15·80	0·70
Fine shallow filter - -	6·87	0·98	10·2	1·62	13·9	1·58	18·20	0·82
Fine deep filter - - -	6·29	0·90	16·9	2·68	19·6	2·22	16·28	0·73
Average - -	6·54	—	—	—	—	—	18·13	—

The ratio figures for the time taken for half the average quantity of salt to wash out in this experiment were thus practically the same as in Salt Experiment 2, viz., 1·0: 1·32 and 1·0 : 1·44 for the two coarse filters and 1·63 : 2·77 and 1·62 : 2·68 for the two fine filters.

In other words, given a filter in the same state, the time of contact is inversely proportional to the rate of flow.

While, therefore, the growth interfered with the progress of the experiment as originally outlined, it has helped in a striking way to shew how close is the relationship between the time of contact and the quality of the effluent.

General Conclusions as to Depth of Percolating Filters.

153. Our Dorking experiments are not completed, and some points are not yet settled, but we think that the results obtained by other workers, together with those arrived at by us, bring out the following points fairly clearly :—

(1) That the deeper the filter the better the effluent. This holds both for fine and coarse material, assuming good distribution and aeration.

(2) For practical purposes and assuming good distribution, the same purification will be obtained from a given quantity of *coarse* material, whether it is arranged in the form of a deep or of a shallow percolating filter, if the volume of sewage liquor treated per cube yard be the same in each case.

Thus, a filter, 3 feet deep, worked at the rate of x gallons per square yard per day, would give similar results to a filter 6 feet deep, worked at the rate of $2\,x$ gallons per square yard.

In the absence of clogging, the balance would be slightly in favour of the deep filter, because the greater the depth the more the errors of distribution would be neutralised. There must always be a limit of shallowness (say 3 feet), beyond which it would be unwise to go, for however good the distribution might be, if a coarse filter were constructed very shallow, a considerable proportion of the sewage would pass through by "short cuts."

(3) With regard to filters of *fine* material, if the liquid to be purified were absolutely free from suspended and colloidal solids, and if thorough aeration could be maintained, the statement just made for filters of coarse material might possibly hold good for filters of fine material also. In practice, however, these conditions can scarcely be maintained with large rates of flow, and we think that the greatest efficiency can be got out of a given quantity of *fine* material by arranging it in the form of a shallow filter rather than of a deep filter. But we are not in a position to make an exact quantitative statement as to the difference in efficiency of the two forms.

It is probable that for the treatment of a strong sewage liquor, the filter should not be quite so shallow as for a weak liquor, but the point has not been fully worked out.

(4) The extent of the purification effected by a percolating filter varies with the average length of time taken by the sewage liquor to pass through the filtering material, assuming that proper aeration of the filter is maintained.

Fowler, 22819.

Size of Material.

154. The size of the filtering material should depend, very largely, upon the amount and character of the suspended matter in the liquid to be filtered. Fine or medium-sized material undoubtedly produces the best effluents, so long as it is kept free from water-logging; but, unless the rate of filtration is slow, such filters soon clog if much suspended matter is contained in the liquid which is being filtered.

At Leeds, screened crude sewage, containing about 50 parts of suspended matter per 100,000, was treated upon filters of coarse material (over 4 inches in diameter) for at least eight or nine months; but it was found that when the same sewage was treated on a Ducat filter constructed of fine to medium clinker ($\frac{3}{8}$-inch to $\frac{5}{8}$-inch diameter), even at a slower rate, the filter became clogged in a month. The rates of filtration were as follows:—

Through the coarse filter ($11\frac{1}{2}$ feet deep)	-	52 gallons per cube yard per day.
Through the fine filter (10 feet deep)	-	45 gallons per cube yard per day.

In considering the question of size of filtering material, the character of the suspended matters in the sewage to be treated must also be taken into account.

No doubt the amount of fibre in the sewage was the chief cause of the very rapid choking of the fine Ducat filter at the Leeds works. As we have already mentioned, this filter became clogged within a month when screened sewage was put upon it, and with septic tank liquor, containing about 18 parts of suspended matter per 100,000, it completely choked after about two and a half years. The rate of filtration during the experiment with septic tank liquor was about 57 gallons per cube yard per day.

155. The following tables give particulars as to the size of filtering material in use at a number of places which we have had under observation.

Place.	Nature of Material.	Size of Material.	Depth of Material.	Amount of suspended matter in liquor treated. Parts per 100,000.		Calculated strength of liquor treated.	Method of Distribution.	Whether delivery of liquid is Continuous or Intermittent.	Rate of filtration in gallons.		Condition of Filters.	Remarks.
				Hourly samples in dry weather.	Average of chance Samples.				Per square yard per 24 hours.	Per cube yard per 24 hours.		
Treatment of Crude Sewage.												
Hendon - -	Clinker.	$\frac{1}{2}$ in. to $\frac{3}{4}$ in.	8 ft.	20	—	107	Tipping troughs.	Continuous.	125	40	Good after eight years.	Experimental Ducat filter. Fixed quantity treated daily.
Leeds - -	Clinker.	$\frac{3}{8}$ in. to $\frac{5}{8}$ in.	10 ft.	—	85	173	Tipping troughs.	Continuous.	83	25	Clogged after one month.	Experimental Ducat filter. Fixed quantity treated daily.
Leeds - -	Clinker.	Over 4 ins.	11·5 ft.	—	53	123	Sprinkler.	Intermittent.	200	52	Choked with growth after 21 months.	Experimental Leeds filter. Fixed quantity treated daily.
Treatment of Settled Sewage.												
Clifton - -	Sand and cinders.	Very fine to coarse.	4 ft.	24	—	123	By fine material on surface.	Intermittent.	20·8	15·6	Good after fourteen years. Filters scraped every three months.	Six times the dry weather flow dealt with in storm times.
Dorking - -	Clinker.	2 ins. to 4 ins.	5 ft. 7 in.	—	9·4	80	Sprinkler.	Continuous.	223	120	Good after two years.	Experimental process. Fixed quantity treated daily.
Leeds - -	Clinker.	Over $1\frac{1}{2}$ ins.	9 ft. 6 in.	—	12	69	Sprinkler.	Continuous.	200	63	Unchanged after one year.	Experimental process. Fixed quantity treated daily.
Little Drayton -	Granite.	$\frac{3}{8}$ in. to $\frac{3}{4}$ in.	7 ft. 6 in.	20	—	165	Tipping troughs.	Continuous.	48	19·5	Upper part of material requires washing after three or four years.	
Treatment of Septic Tank Liquor.												
Accrington -	Coke or clinker.	2 ins. to 4 ins.	9 ft. 3 in. to 7 ft.	—	—	92	Sprinkler.	Continuous.	425	140	Good after four to eight years.	Twice the dry weather flow dealt with.
Birmingham -	Broken brick, granite or slag	Medium to coarse.	—	—	7·3	159	Nozzles.	Continuous.	165	82	Good after three or four years.	
Caterham -	Coke.	$\frac{3}{8}$ in. to 3 ins.	5 ft.	12·6	—	161	Perforated pipes.	Intermittent.	51	30·7	Good after ten years.	Fixed quantity treated daily.
Dorking - -	Clinker.	2 ins. to 4 ins.	5 ft. 7 in.	—	9·5	82	Sprinkler.	Continuous.	223	120	Good after two years.	Experimental process. Fixed quantity treated daily.
Guildford -	Coke.	Over 2 ins.	6 ft.	16	—	125	Sprinkler.	Intermittent.	102	51	Good after nine months.	Experimental process. Fixed quantity treated daily.

Place.	Nature of Material.	Size of Material.	Depth of Material.	Amount of suspended matter in liquor treated. Parts per 100,000. Hourly samples in dry weather.	Amount of suspended matter in liquor treated. Parts per 100,000. Average of chance samples.	Calculated strength of liquor treated.	Method of Distribution.	Whether delivery of liquid is Continuous or Intermittent.	Rate of filtration in gallons. Per square yard per 24 hours.	Rate of filtration in gallons. Per cube yard per 24 hours.	Condition of Filters.	Remarks.
Hanley - -	Saggars.	¼ in. to ½ in.	5 ft.	—	7·6	54 ?	Sprinkler.	Intermittent.	206	124	Upper part of material requires washing after four or five years.	Six times the dry weather flow dealt with.
Huddersfield -	Clinker.	1½ ins. to 4 ins.	7 ft.	—	13	77	Sprinkler.	Continuous.	360	155	Good after one year.	Experimental process. Fixed quantity treated daily.
Leeds - -	Coke.	Over 1½ ins.	9 ft. 6 in.	—	18	76	Sprinkler.	Continuous.	200	63	Good after four years.	Experimental process. Fixed quantity treated daily.
Prestolee -	Cinders and gravel.	Fine to coarse.	5 ft.	3·2	—	22	By fine material on surface.	Intermittent.	92	55	Good after eight years. Surface of material is scraped once a month.	Whole of storm water dealt with.
Rochdale - -	Coke.	1½ ins. to 4 ins.	9 ft.	5·3	—	83	Sprinkler.	Continuous.	424	141	Good after seven years.	Experimental process. Fixed quantity treated daily.
York - -	Clinker.	1½ ins. to 3½ ins.	6 ft. 6 in.	5·3	—	58	Sprinkler.	Continuous.	360	150	Good after six years.	Fixed quantity treated daily.
Treatment of Precipitation Liquor.												
Chorley - -	Sand, polarite and gravel.	Very fine to coarse.	3 ft.	3	—	50	Flush tank.	Intermittent.	525	525	Good after twelve years. Beds washed by upward flow about once a week.	Rather more than dry weather flow dealt with.
Dorking - -	Clinker.	2 ins. to 4 ins.	5 ft. 7 in.	—	5·5	56	Sprinkler.	Continuous.	392	211	Good after two and a half years.	Experimental process. Fixed quantity treated daily.
Horfield - -	Clinker.	3 ins.	7 ft. 5 in.	2·5	—	36	Stoddart trays.	Continuous.	478	190	Good after five years.	Whole of storm water dealt with.
Leeds - -	Coke.	Over 3 ins.	6 ft.	—	6·3	52	Sprinkler.	Intermittent.	100	50	Unchanged after nine months.	During storms rate of filtration was largely increased.
Normanton -	Sand, polarite and gravel.	Very fine to coarse.	3 ft. 3 in.	14·0	—	112	By fine material on surface.	Intermittent.	106	98	Good after ten years. Filters are brushed over after each application of tank liquor and washed by upward flow every three months.	Fixed quantity treated daily.
Withnell - -	Sand, polarite and gravel.	Very fine to coarse.	3 ft.	2·0	—	81	Flush tank.	Intermittent.	68	68	Good after seven and eleven years. Beds raked over every week and washed by upward flow two or three times a year.	Some storm water dealt with.

NOTE.—The calculated "strengths" of the above sewage liquors are only to be taken as approximate and this more especially in the case of the sewages, etc., from Birmingham, Hanley, Huddersfield and Leeds; at those places the 4 hours "oxygen absorbed" figure is obtained with *weak* permanganate and we have only been able to make an *average* allowance for this.

METHODS OF FEEDING PERCOLATING FILTERS.

156. The main object to be aimed at in feeding a percolating filter is to deliver the liquid uniformly over the whole area in such a way that each particle of material receives an equal quantity of liquor.

A distributor should comply with the following requirements:—

It should distribute the liquid uniformly over the whole filtering area;

Its working should not be affected by atmospheric conditions, such as wind, frost, etc.;

It should be capable of adjusting itself to large variations in the flow, *i.e.*, it should deliver equally well the small flow of night sewage and the increased flow during storms.

The distribution should not be liable to be affected by the stoppage of small holes by the suspended matter of the sewage or tank liquor;

It should be easy to clean;

The points at which the moving parts of the distributor are in contact with the stationary parts, or with the parts which have a different motion, should, as far as possible, be separated from the liquid which is being distributed.

In selecting a distributor, it would be necessary to consider the head of water, or other power required to work it, and, of course, the question of cost.

157. At the places which we have had under observation we have had experience of six forms of distribution. We have made no comparative tests of the various forms, and we therefore only propose to offer certain general observations in regard to them.

The forms of which we have had experience may be classified as follows:—

(1) A sprinkler which moves, either automatically or by applied power, dropping or spraying the liquid as it rotates or travels backwards and forwards over an area of filtering material;

(2) A stationary form of distributor, in which the liquid to be distributed is carried over the filter area by means of pipes, and forced under head of water through a large number of small orifices, so that it is broken up into fine jets;

(3) A form of distribution in which definite volumes of liquid are automatically delivered in flushes;

(4) Distribution by means of a very fine material laid on the surface of the filter, the liquid being by this means spread over the whole, or the greater part, of the filtering area;

(5) Dripping trays, a stationary form of distributor, invented by Mr. F. Wallis Stoddart, by which the sewage liquid is carried over a filtering area in perforated trays of corrugated iron, from which it falls upon the filtering material in a succession of drips;

(6) Tipping troughs. A stationary form of distributor, consisting of troughs balanced on pivots in such a way that, when filled with liquid, they tip and then return to their original position.

Type No. 1.—As regards moving sprinklers we may make the following observations :—

(*a*) Unless driven by applied power, which must obviously increase the cost of distribution considerably, they are seriously affected in their distribution by wind, and by severe frost and snow. In the case of light revolving sprinklers, they are not infrequently brought to a standstill by the wind. Where the filter is a small one, this disadvantage may to a considerable extent be overcome by building wind screens round the filter or by raising the retaining walls, but on a large works we should think that this would be impracticable, and with large filters not very effective.

(*b*) Automatic revolving sprinklers, when used intermittently (*i.e.*, when fed from a flushing tank), are capable of adjusting themselves to large variations of flow, but when used continuously, without a flushing tank, their rates of working can only be varied within somewhat narrow limits.

(*c*) The forms of sprinkler in which the tank liquor is delivered to the bed through a number of small holes need a considerable amount of attention. The arms require to be brushed out at least once a day, unless the tank liquor happens to be exceptionally free from suspended matter, or not likely to produce fungoid growths.

Type No. 2.—Distribution by means of perforated pipes or nozzles laid over a filtering area is almost always rather unequal, and this would be a disadvantage, except in the case of fairly deep beds constructed of fine or medium material, or deep beds (say, eight feet or more) of coarse material. This method of distribution, moreover, needs a considerable head of liquid for proper working, and also requires constant attention to keep the pipes and distributing holes clean and free.

At Birmingham, where the nozzle form of distributor is in use on a large scale, for each acre and a half of filter one man is constantly employed night and day in cleaning the nozzles. The constant walking over the surface of a filter is a distinct drawback, but assuming that the occupation is not dangerous to the workman, we think that this method of distribution will, in many cases, be found efficient and cheap.

Watson, 25008. Mr. Watson, of Birmingham, has made a careful comparison of various methods of distribution, and it will be seen from his evidence that, on account of cost, he prefers the system of spraying nozzles to other forms of distribution.

Type No. 3.—This method of distribution would only be suitable in a limited number of cases. Where the distribution is by means of flushes, the upper part of the bed should be made of very fine material, such as sand. With this type of filter the surface has to be constantly washed and cleaned, and it is therefore important that the tank liquor should be comparatively free from suspended matter. Owing to the difficulty of obtaining from a strong sewage a tank liquor containing only a small quantity of suspended and colloidal matter, this type of distribution is not well adapted for cases in which strong sewage has to be treated.

Type No. 4.—The distribution obtained by spreading the liquid to be treated over a filtering area covered with a layer of very fine material, such as soil, sand, or clinker dust, etc., does well either for strong or weak sewages; but unless the fine material on the surface of the bed is kept closely packed, there is danger, when the bed is first brought into use, of the liquid passing too rapidly to the drains. It would seem advisable, therefore, where this method of distribution is adopted, that the filter should be constructed throughout of fine to medium material, except round the drains.

Types Nos. 5 and 6.—Tipping troughs and dripping trays are, in our opinion, more suitable for small than for large installations. They can adapt themselves to large variations of flow, and in the case of small or medium-sized works, where constant supervision is not available, this is a great advantage. We may add that these trays are better suited for the distribution of a large volume of weak liquid than a small volume of strong liquid.

The distribution is seldom perfect by either of these forms of distributor, and consequently it is advisable to have deep beds where they are adopted. Further, owing to the fact that the delivery of liquid in both cases is more or less constant, medium-sized or coarse material should be used, to prevent ponding.

A certain amount of supervision is necessary as a tray may become blocked or a trough may fail to tip. The trays would require to be looked at about once a day, we think, and tipping troughs about twice a day; but, beyond this, little attention is required. The distribution in both these forms is divided up into a number of units, and it is very unlikely that more than one or two units would get out of order at a time and that the distribution would be bad over a whole filtering area.

That tipping troughs are liable to be completely put out of action by severe frost we have seen exemplified at Little Drayton, and although we have had no experience of the same kind with regard to the trays, we should think that these were also liable to be affected by severe frost, though in their case distribution would never cease altogether.

Risk of Nuisance.

158. All forms of distribution on percolating filters are liable to give rise to nuisance from smell, if a strongly smelling liquor has to be dealt with. In the case of trays or tipping troughs the smell is confined more or less to the immediate vicinity of the filter, and it may be largely done away with at small works by providing an inexpensive form of cover for the filter. The nozzle form of distributor is naturally the most liable to give rise to smell, but moving sprinklers are almost equally bad in this respect.

Some Observations on the Most Convenient Superficial Area for a Percolating Filter.

159. So long as due regard is had for economy, the main consideration in laying out an area of percolating filters is to arrange the area so that portions of it may be put out of work without interfering with the general working of the plant.

If, for instance, at a small sewage works the whole of the sewage was treated upon one percolating filter fed by one sprinkler, any stoppage of that sprinkler would, unless land or some other means of disposal were available, result in the temporary discharge of a large quantity of unpurified sewage into the watercourse.

Experience has not shown that it is *necessary* for purposes of aeration to expose the sides of a percolating filter to the atmosphere, in order to obtain good results, and there would seem to be no reason, beyond engineering considerations, such as configuration of site, etc., for splitting up an area of percolating filter into units, provided that any part of that area could be cut out and rested, when necessary, without interfering with the general purification. The particular arrangement of the works would therefore depend very largely upon the form of distributor employed.

The size of a revolving distributor, for instance, has economic limits, and if this method of distribution were adopted the filter area would have to be split up into units corresponding with these limits.

The method of distribution by flushing fixed quantities of sewage liquid over percolating filters, constructed with a surface layer of very fine material, necessitates that the filter units should be small. Otherwise the flush of liquor cannot be made to spread evenly over the whole surface of the filter. This kind of filter has also to be washed or scraped at short intervals of time, and allowance must consequently be made for this.

Distribution by a power-driven distributor moving over a rectangular bed also has its limits, for, although the working of such a distributor can be regulated so as to rest the ends of a rectangular bed, it would appear to be difficult to feed the

* Some experiments which we carried out at Hendon, with the Ducat filter, indicated that open sides may be of advantage for the treatment of crude-screened domestic sewage, on a rather fine perolating filter Other work has prevented us from completing these experiments.

ends while resting the middle portion of the area. Further, if the bed were *very* long, large quantities of liquor would have to be fed on to each portion of filter at long intervals of time, instead of small quantities at short intervals.

With stationary distribution by means of nozzles, perforated pipes, dripping trays or tipping troughs, there would appear *in principle* to be no limit of size, for portions of a large area fed by such means could be cut out or brought in at will, without interfering with the general purification.

Where moving sprinklers are used, it would be cheaper to limit the number of units to a minimum, but the whole filtering area should comprise not less than three units so as to allow of cleaning and resting.

In the arrangement of a percolating filter area at a very large works, other considerations would have to be taken into account, such, for example, as the size of feed pipes, and the distance which the workmen would have to walk upon the material in order to get at different parts of the filter.

In regard to this question we may refer, particularly, to the evidence of Dr. Fowler, 23020, Mr. Watson, 25015, Dr. Reid, 24432 (131), and Messrs. Willcox and Raikes, 26114.

Construction of the Base of Percolating Filters.

160. In a percolating filter of *coarse* material, large quantities of suspended matter quickly work their way through the filter. If this suspended matter is not allowed to come away with the effluent, the bottom layers of the filter will become choked, and this will interfere with the working of the filter, not only for mechanical reasons, but also by preventing aeration. In such a filter, therefore, it is necessary to make provision for the free passage of suspended matter through the material and into the effluent drains, so that it can be completely carried away from the bed and dealt with subsequently.

In a percolating filter of *medium* or *fine* material, where the bulk of the suspended matter is caught and held in the upper part of the filter, the free base would not seem to be an absolute necessity. If, however, the suspended matter is not removed from the upper part of the filter by washing or riddling, it will eventually find its way to the bottom of the filter.

In any case the working of a percolating filter depends primarily upon the free passage of air through the bed, and, for this reason, we should say, in general, that it is advisable to construct the lower portions of all percolating filter, fine as well as coarse, as open as possible.

If, in a filter constructed of medium or fine material, a bottom layer of large pieces is relied upon wholly for the aeration of the bed and for the free passage of liquid to the drains, it is obvious that great care must be taken in selecting this coarse material. Any serious disintegration at the bottom of the filter would result in parts of the filter becoming water-logged.

Choking of Percolating Filters.

161. Unless the material is coarse enough to allow the free passage of suspended matter, percolating filters are liable to become choked. Within ordinary practical limits, the rate of choking would depend upon the actual quantity of suspended matter delivered to the surface of the bed. At Leeds, for instance, it was found that carefully screened sewage, containing 80 parts of suspended matter per 100,000, when put upon a percolating filter composed of clinker $\frac{3}{8}$ inch to $\frac{5}{8}$ inch diameter, ten feet deep, had the effect of completely choking the surface within a month, notwithstanding the fact that the rate of filtration never exceeded 25 gallons per cube yard per day. When, however, septic tank liquor containing only about 18 parts of suspended matter per 100,000 was substituted for the screened sewage, the same filter gave good results without clogging for two years, though the rate of filtration was doubled. At the end of that time it was necessary to rest the bed and fork the surface, and after three years, owing to internal clogging, it became necessary to stop the experiment.

If a clogged filter of medium or fairly coarse material is rested, the suspended matter which causes the choking becomes granular, and can eventually be washed out of the filter. To some extent this applies also to a filter composed of very fine material, but in that case by far the greater proportion of the suspended matter remains on or near the surface and can only be got rid of by removing the clogged material and washing it, or exposing it for some time to the air, and eventually riddling it dry. When coarse material is used in a percolating filter there is apparently little danger of the filter becoming clogged, unless the sewage contains much fibre or is liable to give rise to fungoid growths, or unless serious disintegration of the material takes place. We have had no experience of such a filter becoming clogged with suspended matter when dealing with domestic sewage. At Accrington, coarse percolating filters have been in use for the treatment of septic tank liquor for eight years, and have not clogged. At Horfield, a coarse percolating filter treating precipitation liquor and fed by means of dripping trays ran uninterruptedly until it was dismantled after five years' work. At York, coarse filters have been in use for the treatment of septic tank liquor, without interruption, for four years. There are, in fact, a number of such instances. This kind of filter, however, seems to be liable to choke as the result of surface growths (*see* page 97). Where there is much fibre in the liquid to be treated (and the same thing would no doubt apply to grease and hops, etc.), percolating filters of even very coarse material may choke up. At Leeds, a percolating bed which was constructed of coarse coke, showed signs of becoming choked after having received septic tank liquor for eight and a half months. The primary cause of the choking was, we think, the fibrous character of the suspended matter, but there was a considerable development of growth on the surface of this bed at the same time.

The choking of a percolating filter constructed of medium-sized material (say $\frac{1}{4}$ inch to $\frac{5}{8}$-inch diameter) takes place at or near the surface, the material below this remaining fairly clean. We have seen examples of this at Salford, Hanley, Chesterfield, Birmingham, and Hendon, though at none of these places was the choking serious. At Market Drayton and Leeds, however, the upper portions of the filters had to be washed or renewed after about three years' work. The following table shows the amount of suspended matter, the rate of filtration, and the condition of the filters at the above places :—

Place.	Nature of material.	Size of material.	Amount of suspended matter in tank liquor treated. Parts per 100,000.	Rate of filtration in gallons.		Condition of filters.
				Per square yard per 24 hours.	Per cube yard per 24 hours.	
Leeds - - -	Clinker	$\frac{3}{8}$ in. to $\frac{5}{8}$ in.	80	83	25	Clogged after 1 month.
Market Drayton -	Granite	$\frac{3}{8}$ „ $\frac{3}{4}$ „	25	50	20	Upper part of material required washing after about 4 years' work.
Hendon - -	Clinker	$\frac{1}{2}$ „ $\frac{3}{4}$ „	20	125	40	Good after 8 years.
Leeds - - -	„	$\frac{2}{3}$ „ $\frac{5}{8}$ „	18	200	57	Bed seriously clogged after $2\frac{1}{2}$ years.
Chesterfield -	„	$\frac{1}{4}$ „ 2 „	12	90*	40*	Good after 6 years.
Birmingham -	Broken brick and granite	$\frac{1}{2}$ „ 3 „	8	155	77	Good after 3 or 4 years.
Hanley - -	Saggars	$\frac{1}{4}$ „ $\frac{1}{2}$ „	5	206	124	Upper part of material would probably require washing every 4 or 5 years.
Salford - -	Clinker	$\frac{3}{16}$ „ $\frac{3}{4}$ „	3	318	151	Good after 5 years. Top foot of material renewed on 10 per cent of area after 3 or 4 years, and rest of area dug over.

* Dry-weather rates of flow. In storm times these filters take four times the dry-weather flow.

We have had no experience of the washing of percolating-filter material on a practical scale; but, from the evidence given as to the cost of washing contact-bed material, we should estimate that the cost would be approximately 1s. 6d. to 2s. 6d. per cube yard, if done by machinery on a large scale, and from 2s. 6d. upwards per cube yard, if done by hand on a small scale.

Growths on Percolating Filters

162. At a number of places thick, gelatinous, fungoid growths have at certain periods of the year (usually in the winter or early spring) developed upon the surfaces of percolating filters to such an extent as to cause serious ponding and consequent deterioration of the filter effluent. On the other hand, at other places, where apparently similar growths are present in small quantities on the surface of the material, they do not increase to any marked extent, and no ponding arises from this cause. Tables I. and II. give examples of each kind of place.

Table I.—Places where growths upon the surface of percolating filters have caused trouble.

Place.	Material used in filter.	Size of Material.	Mode of Distribution.	Whether delivery of liquor is continuous or intermittent.	Kind of liquor treated.	Amount of suspended matter in the liquor. Parts per 100,000.	Remarks as to growths.
Dorking	Clinker.	Coarse to medium.	Sprinkler.	Continuous.	Precipitation liquor.	8	The filters were started on Nov. 16th, 1905, and a pinkish-yellow filamentous growth made its appearance a fortnight later. This flourished until May of the following year, when it died away. During the last five weeks of this period the effluent from the filter was bad.
	Clinker.	Coarse to medium.	Sprinkler.	Continuous.	Septic tank liquor.	8·1	In both these cases, a grey-brown amorphous growth made its appearance at the same time as the growth on the filter treating precipitation liquor, but it did not flourish to such an extent, and never interfered seriously with the working of the filter. It practically disappeared during the early part of May.
	Clinker.	Coarse to medium.	Sprinkler.	Continuous.	Settled sewage.	10·5	
Guildford	Coke.	Coarse.	Sprinkler.	Intermittent.	Septic tank liquor.	15·9	This experimental filter was started in August, 1906. A grey-brown filamentous growth appeared on surface of the coke during the last months of that year, and increased seriously after frosty weather in January, 1907. The growth began to die away in the early summer.
Kingston	Clinker.	Coarse.	Sprinkler.	Continuous.	Precipitation liquor.	1·5	A short fibred grey growth appears annually on the surface of the filter, commencing about November and dying off in March. In the winter months it forms an almost impervious mat on the surface of the filter, the effluent becoming bad in consequence.
Leeds	Clinker.	Coarse.	Sprinkler.	Continuous.	Septic tank liquor.	18	The filter was started on March 9th, 1899, and ran till May 8th of the same year, when the effluent deteriorated in quality owing to the bed having become covered with an abundant gelatinous mycelium-like growth (pylobolus). On July 10th some very coarse coke was put on the surface of the bed, and from that time it was found possible to run for periods of about three months before the surface choked with the growth. When this occurred the coke was simply forked over.
	Clinker (6 inches of gas coke on surface).	Very coarse.	Sprinkler.	Continuous.	Crude sewage.	5·3	The filter was started on December 23rd, 1901. Almost from the first trouble arose from the thick pylobolus growth forming on the surface; this closed the interstices of the gas coke, and so gave rise to ponding and bad distribution. On March 1st, 1902, the coke was removed, and the bed from that time gave good results until the winter of 1902–3, when choking again occurred.

TABLE II.—Places where percolating filters have been run without any trouble from growths.

Place.	Material used in filter.	Size of material.	Mode of distribution.	Whether delivery of liquor is continuous or intermittent.	Kind of liquor treated.	Amount of suspended matter in the liquor. Parts per 100,000.	Remarks as to growths.
Accrington - - -	Clinker	Coarse	Sprinkler	Continuous	Septic tank liquor	19	Only very slight signs of growth on the surface of the material after six years' work.
Birmingham - -	Clinker	Coarse to fine	Nozzles	Intermittent	Septic tank liquor	7·3	Only slight signs of growth after a year.
	Broken brick	Coarse to fine	Nozzles or sprinkler	Continuous or intermittent	Septic tank liquor	7·3	Only slight signs of growth after a year.
	Broken granite	Coarse to fine	Nozzles or sprinkler	Continuous or intermittent	Septic tank liquor	7·3	Only slight signs of growth after a year
Chorley - - - -	Sand	Very fine	Flushing tank	Intermittent	Precipitation liquor	2	No growth after eight years. Filters washed every week.
Hanley - - - -	Saggars	Fine	Sprinkler	Intermittent	Septic tank liquor	4·4	No growth after four years.
Horfield - - -	Clinker	Coarse	Dripping trays	Continuous	Precipitation liquor	2·5	No growth after four years
Huddersfield - - -	Clinker	Coarse to medium	Sprinkler	Continuous	Septic tank liquor Precipitation liquor Settled sewage	 13·1 7·0	No serious signs of growth on any beds.
York - - - -	Clinker slag, coke, broken brick	Coarse to medium	Sprinkler	Continuous	Septic tank liquor	5·3	No growth after four years.

163. So far as we are aware, such growths have not been made the subject of systematic study in connection with sewage disposal, and little appears to be known as to the conditions under which they flourish. As will be seen from Table I., however, a pyloholus growth appeared upon the surface of a percolating filter treating septic tank liquor at the Leeds sewage works. In their Report on Experiments in Sewage Disposal, City of Leeds, 1905, p. 140, Colonel Harding and Mr. Harrison make the following remarks on the subject:—

"A few words must be added in regard to the difficulty of the fungoid "growths which arise in dealing with Leeds sewage on percolating filters, and "which, with any but very coarse material, soon choke the air spaces, and cause "the sewage to pond on the surface. The growths were less with partly settled "sewage than with the crude sewage and as in other cases they did not spread far "down into the filter, not more than from 6 to 12 inches at the most, it would "seem that light is required for their development."

"On the other hand, the holes in the sprinkler tubes were constantly choked "with these growths, so that they required to be daily cleansed; but it is more "likely that this was due to the fungus which forms in the open channels leading "to the sprinkler being washed forward into the tubes than to the growths arising "in the tubes themselves. It is quite possible that sewage thoroughly well settled "may give rise to fungoid growths, the detritus from which may cause suspended "matters to appear in a filtrate."

"The question of these growths and the circumstances which favour their "development is one that should be further investigated."

164. As the use of percolating filters is likely to spread in the future, we are impressed with the need for practical experiments which have for their object either the prevention or the destruction of the growths on the surfaces of such filters.

That growths of this kind can be destroyed is shown by an experiment (suggested by Dr. Houston and Mr. Colin Frye) recently carried out on a small scale upon the surface of one of our experimental filters at Dorking. In March, 1907, the surface of this filter (which at that time treated septic tank liquor) was covered with a considerable layer of gelatinous growth, sufficient to cause local ponding in the tracks of the sprinkler jets. On March 16th the filter was rested for twenty-four hours in dry weather, and at the end of that time the surface was divided up into eight equal segments (1.6 square yards each), and seven of these were treated with the following reagents, the eighth segment being left untouched:—

(1) Powdered quicklime.
(2) Bleaching powder.
(3) A 20 per cent. solution of "Chloros."
(4) A 20 per cent. solution of copper sulphate
(5) A 20 per cent. solution of ferrous sulphate.
(6) A 20 per cent. solution of caustic soda.
(7) A 20 per cent. solution of sulphuric acid.

In the case of (1) and (2), sufficient of the dry solid was used to cover the surface with a fine layer of powder, while in the case of the other five segments one litre of each solution was applied to the material with a brush, the filter being then left resting for a further period of twenty-four hours.

At the end of this time, the segment which had been treated with caustic soda had undergone a distinct change in appearance, the clinker being perfectly clean on the upper side, though the under side was still covered with a slimy layer of half-dissolved growth. Of the other six segments, none showed any marked destruction of the growth, but the copper and iron sulphates had stained their segments green and rusty brown respectively. The filter was started again at 3 p.m. on the same day. A very large quantity of coarse brown solid matter (20 to 30 parts per 100,000) came away in the filter effluent during the first hour, but the quantity gradually decreased to about 6

parts per 100,000 after 24 hours. The samples taken during the first hour went putrid upon incubation, this being no doubt chiefly due to the outflush of solids, but otherwise the working of the filter was not seriously upset, though the nitric nitrogen in the effluent fell from 2 parts to 1 part per 100,000 for some days, eventually rising again to 2 parts on March 25th.

On April 22nd there were again signs of local ponding on the surface of the filter, but the growth on that segment which had been treated with caustic soda was considerably less than on the other segments. It was therefore thought desirable to try the application of a 20 per cent. solution of caustic soda to the whole surface of the filter. This was accordingly done, two gallons of the solution being used for the purpose. The procedure otherwise, *i.e.*, as regards the resting of the filter, was exactly the same as in the first experiment.

On the following morning the surface of the clinker was covered with a white deposit of sodium carbonate, and, on re-starting the filters shortly afterwards, a great quantity of dark brown solid matter came away in the effluent. Samples of effluent drawn for the first two hours readily putrified upon incubation. After twenty-four hours the effluent when freed from solid matter was normal, but a large quantity of suspended solids continued to come away with the effluent for about a week.

As in the case of the first experiment, the working of the filter, apart from the flush-out of solids, was not seriously upset, and after the first two hours from the restart there was no fall in the figure for oxidised nitrogen.

The exposed surface of the clinker was completely cleaned by this application of caustic soda solution, though a considerable amount of growth still adhered to the under side of the larger pieces of material. All ponding, however, disappeared, and no further growth of any consequence made its appearance for some months. The cost of the treatment, including labour, was 2½d. per square yard, but this would no doubt be materially reduced when carried out on a large scale.

Probably three such applications of 20 per cent. caustic soda would be necessary to keep the growth down during the winter or early spring months on the filter at Dorking.

165. Generally speaking growths do not appear to flourish on the surface of percolating filters constructed of fine material, but whether this is due to the size of the material or to the fact that filters of fine material are usually fed intermittently, we cannot say. Colonel Harding and Mr. Harrison, in an experiment at Leeds, found that they could keep down growth on a coarse-grained filter by substituting an intermittent sprinkler for a continuous one.

Our experiments seem to indicate that growths flourish most on filters treating precipitation liquor. This suggests that the use of chemicals (especially soluble sulphates) may influence their development, but, on the other hand, precipitation liquor usually contains considerably less suspended matter than other tank liquors, and a larger volume of it is for this reason generally treated per cube yard.

As regards the growths in channels along which effluents flow, they seem to require, for their development, an aerated but still unpurified sewage liquid, and it is possibly for this reason that they are generally more abundant in channels conveying dilute sewage liquids than in channels conveying strong sewage liquids, especially if the suspended matter is removed.

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Some Observations as to the Relative Cost of Contact Beds and Percolating Filters.

166. On pages 36–43 of this Report we have made some observations on the relative cost and efficiency of preliminary processes for the removal of suspended matters from sewage, and we propose here to make a similar comparison between the two types of artificial filter usually adopted for the further purification of the sewage, and commonly known as "contact beds" and "percolating filters." As in the case of the preliminary processes, the cost of filters necessarily varies with local conditions, and no figures can be given which would be generally applicable. Following the plan adopted in the case of the preliminary processes, however, we propose to compare the two types of filters in a hypothetical case in which we assume :—

That ample fall is available ;

That the sewage is of a normal domestic character and of average strength ; *i.e.*, a sewage which would require about 100 parts of oxygen,* by weight, for the oxidation of the organic matter contained in 100,000 parts of sewage ;

That the flow of sewage is 1,000,000 gallons per day in dry weather ;

That in times of storm twice the dry weather flow is passed through the filters.

For the purpose of this comparison, we assume that the sewage has been subjected to preliminary tank treatment for the removal of suspended matter, and that in each case a satisfactory final effluent is to be produced.

We have not considered it necessary to compare the costs of all the modifications of percolating filters and contact beds of which there are examples, but have confined our comparion to percolating filters of coarse material, nine feet deep, and contact beds composed, for the most part, of medium-sized material, but having rather coarse material round the drains and a layer of fine material on the surface.

Mr. G. B. Kershaw, our Engineer, has prepared detailed drawings of the two kinds of filter, when used in conjunction with each of five different tank treatments, and, from these drawings has taken out quantities. The filters are all assumed to have been constructed on the same basis. The concrete flooring for the percolating filters, for example, has been assumed to be practically the same thickness as the concrete flooring for the contact beds, and the cost of concrete has been taken at a fixed price throughout. The class of work has been taken to be of the best kind, the walls and the floors of the contact beds, for instance, being made thoroughly water-tight by rendering with cement. It is due mainly to this fact that our estimates for the cost of contact beds are high. At some places a cheaper form of construction than we have assumed has been adopted. At Burnley, for instance, no concrete was used, and the beds, which are 3 feet in depth, cost approximately £1,300 per acre. At Manchester, where concrete was used, but where no rendering was done, the cost amounted to between £2,500 and £3,000 per acre for beds of the same depth. In Mr. Kershaw's estimates, the cost is about £5,700 per acre.

167. The working capacities of both contact beds and percolating filters depend to a large extent upon the strength of the liquor passed on to them and the amount of suspended matter contained in such liquor. In the following table, the strength of the tank liquor which is produced from our hypothetical sewage by each of the five preliminary processes, the amount of suspended matter in the liquor in each case, and the rate of filtration in each type of filter, are given :—

* This would generally be equivalent to about 10 or 12 parts per 100,000 of "oxygen absorbed" in four hours from strong permanganate.

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Preliminary Process.	Strength of Tank Liquor, stated in parts by weight of oxygen per 100,000 required for the oxidation of the organic matter.	Amount of Suspended Matter in Tank Liquor (parts per 100,000).	*Contact Beds.		*Percolating Filters.	
			Rate of Filtration per cube yard per day (dry weather flow).	Cubic Content of Filtering Material required to treat one million gallons per day (dry weather flow).	Rate of Filtration per cube yard per day (dry weather flow).	Cubic Content of Filtering Material required to treat one million gallons per day. (dry weather flow).
			Gallons.	Cubic yards.	Gallons.	Cubic yards.
Quiescent settlement, with chemicals.†	50	1 to 4	140	7,143	175	5,714
Continuous flow settlement, with chemicals.	60	3 to 6	85	11,765	150	6,666
Quiescent settlement, without chemicals.	70	5 to 8	55	18,182	100–125	8,928
Continuous flow settlement, without chemicals.	80	10 to 15	40	25,000	75–100	11,494
Septic tanks - - -	80	10 to 15	40	25,000	75–100	11,494

Initial Cost of Contact Beds and Percolating Filters.

168. The following table gives Mr. Kershaw's estimates of the constructional cost of percolating filters and contact beds required to treat a dry weather flow of 1,000,000 gallons per day of our hypothetical sewage on the above basis. The estimates include the sum of 15 per cent. for engineering and contingencies.

Preliminary Process.	Contact Beds.	Percolating Filters.
	£	£
Quiescent settlement, with chemicals - - - -	8,527	7,376
Continuous flow settlement, with chemicals - - -	14,898	8,836
Quiescent settlement, without chemicals - - -	22,080	10,596
Continuous flow settlement, without chemicals - -	26,846	13,824
Septic tanks - - - - - - - - - -	26,846	13,824

The principal items in the estimates for both kinds of filters are: filtering medium, concrete in walls and floors and rendering; and excavation in the case of the contact beds.

The figures for these items are given in the following tables:—

Contact Beds.

Preliminary Process.	Cost of Filtering Medium.	Cost of Concrete in Floors and Walls.	Cost of Rendering.	Cost of Excavation.
	£	£	£	£
Quiescent settlement, with chemicals - -	3,777	2,545	675	Single set of beds; very little excavation. ‡
Continuous flow settlement, with chemicals -	3,545	3,882	1,350	885
Quiescent settlement, without chemicals -	5,431	5,461	1,650	1,204
Continuous flow settlement, without chemicals.	7,231	7,038	2,171	1,722
Septic tanks - - - - - -	7,231	7,038	2,171	1,722

* The quality of the effluents produced by the ten plants would, of necessity, not be identical. The average quality as expressed in terms of oxidizability of effluent (see paragraphs 178 and 179) would be something like +2 for the double contact effluents and—2 for the percolation effluents.

† In the case of quiescent settlement with chemicals, we have allowed for single contact only; in the other cases, for double contact.

‡ We have assumed in our hypothetical case that the primary beds are practically out of ground, and that excavation is required only in the case of the secondary beds.

Percolating Filters.

Preliminary Process.	Cost of Filtering Medium.	Cost of Concrete in Floors and Walls.	Cost of Rendering.
	£	£	£
Quiescent settlement, with chemicals - - - -	1,951	2,617	269
Continuous flow settlement, with chemical - - - -	2,431	3,271	336
Quiescent settlement, without chemicals - - - - -	4,375	5,889	605
Continuous flow settlement, without chemicals - - - -	5,833	7,851	806
Septic tanks - - - - - - - - - -	5,833	7,851	806

Effluent Settling Tank.

169. In our hypothetical case, a tank is provided for the settlement of the effluent from the contact beds, as well as from the percolating filters. Some means are needed in the case of coarse percolating filters for the settlement of the effluent solids; and in the case of the contact beds we have assumed that a tank was required for the purpose of rendering the discharged liquid uniform in quality, and thus preventing the possible discharge of a putrescible effluent during the first flush, and, more especially, of putrescible solids. The effluent tank is of the Dortmund type, having a capacity of about 84,000 gallons, so as to provide for a stay in the tank of about two hours in each case. The total cost of this tank is calculated to be £682.

Loan Charges.

170. The following table gives the area and the assumed cost of the land occupied by the installations.

We have taken the price of land throughout at £100 per acre.

Preliminary Process.	Contact Beds.		Percolating Filters.	
	Land required (acres).	Cost of Land.	Land required (acres).	Cost of Land.
		£		£ s. d.
Quiescent settlement, with chemicals - - -	1·26	126	0·73	73 0 0
Continuous flow settlement, with chemicals -	2·03	203	0·91	91 0 0
Quiescent settlement, without chemicals- - -	3·21	321	1·095	109 10 0
Continuous flow settlement, without chemicals -	4·18	418	1·46	146 0 0
Septic tanks - - - - - - -	4·18	418	1·46	146 0 0

Assuming that the loan is raised at 3½ per cent. interest per annum, and is repayable in equal annual instalments over a period of thirty years, the annual loan charges on the complete installations would be as follows :—

Preliminary Process.	Contact Beds.		Percolating Filters.	
	Loan charges in respect of Contact Bed Installation.		Loan charges in respect of Percolating Filter Installation including charges in respect of sprinklers.	
	Per annum.	Per million gallons (dry weather flow).	Per annum.	Per million gallons (dry weather flow).
	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Quiescent settlement, with chemicals	507 3 9	1 7 10	470 19 7	1 5 10
Continuous flow settlement, with chemicals	858 4 0	2 7 0	558 11 3	1 10 7
Quiescent settlement, without chemicals	1,255 2 9	3 8 9	662 9 2	1 16 3
Continuous flow settlement, without chemicals	1,519 6 3	4 3 3	854 8 5	2 6 10
Septic tanks	1,519 6 3	4 3 3	854 8 5	2 6 10

Labour and Supervision.

171. For the contact bed installations, we assume that the services of two men (one for the day and one for the night) would be required, and for the percolating filter installations, the services of one man.

Taking the labourer's time at 21s. a week, and including one-third of the manager's time at a salary of £130 per annum (say, £43), the cost of labour and supervision in connection with the installations would be as follows :—

Preliminary Process.	Contact Beds.		Percolating Filters.	
	Per annum.	Per million gallons (dry weather flow).	Per annum.	Per million gallons (dry weather flow).
	£	s. d.	£	s. d.
Quiescent settlement, with chemicals	152	8 4	98	5 4½
Continuous flow settlement, with chemicals	152	8 4	98	5 4½
Quiescent settlement, without chemicals	152	8 4	98	5 4½
Continuous flow settlement, without chemicals	152	8 4	98	5 4½
Septic tanks	152	8 4	98	5 4½

Cost of washing and renewing Filtering Medium.

Contact Beds.

172. According to the evidence, which is dealt with in another part of this Report, we find that the average cost of removing, washing, replacing, and making good the material of a contact bed, by machinery, is about 1s. 6½d. per cube yard, exclusive of cost of washing plant.

In the present calculations we assume that the cost per cube yard of washing, etc., is 1s. 7d., and that the material in the primary beds would require washing every four years, and that in the secondary beds every ten years.

On these assumptions, one acre of primary beds, 3 feet deep, would cost £383 every four years for washing and renewal, or about £96 per annum ; and one acre of the secondary beds, £383 every ten years, or £38 6s. per annum.

Percolating Filters.

173. So far as our experience of percolating filters of coarse material has gone, we think it may be taken that the material of these filters will last for a very long period of time, if a few inches on the top of the filter are removed and renewed occasionally. At Accrington, Rochdale, and York, beds of this kind, constructed both of coke and clinker, have been in constant use for eight years. At Horfield a clinker bed, dismantled after five years' use, was found to be in almost the same condition as when it was started. We do not propose, therefore, to add anything to the cost of our percolating filter installations for washing and renewal of material.

Plant special to Percolating Filters.

174. We have assumed that the life of rotary sprinklers treating domestic sewage is ten years, and have therefore calculated the loan charges on this period.

At Accrington the annual cost of repairs to an automatic rotary sprinkler, taken over a period of three years, was found to average 18s. 4d. In our calculations, we have taken the cost of repairs at £1 per sprinkler per annum.

The following table shows our estimates of the cost of washing contact bed material. and, in regard to percolating filters, the sums required for repairs and loan charges in respect of sprinklers :—

Preliminary Process.	Contact Beds.		Percolating Filters.			
	Annual Charges in respect of Washing and Renewal of Beds.	Cost per million gallons in respect of Washing and Renewal of Beds.	Annual Loan Charges in respect of Sprinklers based on a ten year period.	Loan Charges in respect of Sprinklers per million gallons (dry weather flow).	Annual Cost of Repairs to Sprinklers.	Cost of Repairs to Sprinklers per million gallons (dry weather flow).
	£ s. d.	s. d	£ s. d.	s. d.	£	d.
Quiescent settlement, with chemicals.	141 2 5	7 9	28 17 2	1 7	4	2½
Continuous flow settlement, with chemicals.	169 8 6	9 3	36 1 6	2 0	5	3¼
Quiescent settlement, without chemicals.	266 10 1	14 7	43 5 9	2 4½	6	3¾
Continuous flow settlement, without chemicals.	360 18 4	19 9	57 14 5	3 2	8	5¼
Septic tanks	360 18 4	19 9	57 14 5	3 2	8	5¼

Total Cost for Filtration alone.

175. The total cost of the contact bed and percolating filter installations, including loan charges, labour and supervision, etc., according to the foregoing calculations, would be as follows :—

Preliminary Process.	Contact Beds.		Percolating Filters.	
	Per Annum.	Per Million Gallons (dry weather flow).	Per Annum.	Per Million Gallons (dry weather flow).
	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Quiescent settlement, with chemicals	800 16 2	2 3 11*	572 19 7	1 11 5
Continuous flow settlement, with chemicals.	1,179 12 6	3 4 7	661 11 3	1 16 3
Quiescent settlement, without chemicals	1,673 12 10	4 11 8	766 9 2	2 1 11
Continuous flow settlement, without chemicals.	2,032 4 7	5 11 4	960 8 5	2 12 8
Septic tanks	2,032 4 7	5 11 4	960 8 5	2 12 8

* Single contact assumed in this case.

Total Cost of Complete Treatment.

176. The total cost of each of the preliminary processes has been shown in another part of this Report. Adding this to each of the filtration processes, we arrive at the following figures for the total cost of the complete treatment of a dry weather flow of 1,000,000 gallons of sewage per day.

Per Annum.

Preliminary Process.	Contact Beds.			Percolating Filters.		
	Total Cost of Preliminary Treatment.	Total Cost of Filtration Process.	Total Cost of Complete Treatment.	Total Cost of Preliminary Treatment.	Total Cost of Filtration Process.	Total Cost of Complete Treatment.
	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Quiescent settlement, with chemicals.	1,258 0 9	800 16 2*	2,058 16 11	1,258 0 9	572 19 7	1,831 0 4
Continuous flow settlement, with chemicals.	1,134 19 11	1,179 12 6	2,314 12 5	1,134 19 11	661 11 3	1,796 11 2
Quiescent settlement, without chemicals.	724 7 9	1,673 12 10	2,398 0 7	724 7 9	766 9 2	1,490 16 11
Continuous flow settlement, without chemicals.	564 12 8	2,032 4 7	2,596 17 3	564 12 8	960 8 5	1,525 1 1
Septic tanks - - -	629 4 11	2,032 4 7	2,661 9 6	629 4 11	960 8 5	1,589 13 4

Per Million Gallons (dry weather flow).

Preliminary Process.	Contact Beds.			Percolating Filters.		
	Total Cost of Preliminary Treatment.	Total Cost of Filtration Process.	Total Cost of Complete Treatment.	Total Cost of Preliminary Treatment.	Total Cost of Filtration Process.	Total cost of Complete Treatment.
	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Quiescent settlement, with chemicals.	3 8 11	2 3 11*	5 12 10	3 8 11	1 11 5	5 0 4
Continuous flow settlement, with chemicals.	3 2 2	3 4 7	6 6 9	3 2 2	1 16 3	4 18 5
Quiescent flow settlement, without chemcals.	1 19 8	4 11 8	6 11 4	1 19 8	2 1 11	4 1 7
Continuous flow settlement, without chemicals.	1 10 11	5 11 4	7 2 3	1 10 11	2 12 8	4 3 7
Septic tanks - - -	1 14 6	5 11 4	7 5 10	1 14 6	2 12 8	4 7 2

177. On the basis which we have adopted, purification of sewage (after preliminary treatment) by means of percolating filters costs only about two-thirds as much as purification by double contact beds.

Where, however, the sewage has first been subjected to quiescent settlement, with chemicals, and single contact is sufficient to produce a satisfactory effluent, the cost becomes more nearly equal, though percolating filters are, even in that case, slightly cheaper.

The cost depends, of course, very largely on the kind of construction adopted.

Our estimates for the cost of double contact beds per acre, 3 feet deep, including filtering material, concrete, rendering, drains, distribution channels, engineering and contingencies, etc., amount approximately to £5,700 per acre. If the beds were built by simple excavation and banking, as is permissible in heavy clay soil, the cost would be very considerably reduced.

We have taken the price of filtering material at 6s. per cube yard, placed in position in the beds, which may be considered a fair average, though evidence shows the price has in some cases been much lower. Since this item alone amounts to about £1,396 per acre, 3 feet deep, it is at once apparent how largely the price of filtering material influences the cost of treatment.

* Single contact assumed in this case.

RELATIVE EFFICIENCY OF CONTACT BEDS AND PERCOLATING FILTERS.

178. Sewages vary in composition, not only in regard to the degree of dilution to which they are naturally subjected, but also in regard to the proportion in which different kinds of organic matter are present in them, and we are not aware of any really accurate method by which the work done by different filters, treating different sewages, can be compared.

We have, however, found it convenient to adopt, for the purpose of comparing the results obtained at different places, a unit of purification, which is based on the oxidizability of the sewage and the oxidizability of the filtrate, after giving credit for the oxygen contained in the effluent in the form of nitrate.

This basis for a unit was suggested by Dr. McGowan.

The unit of time we have taken as 24 hours, the unit of quantity as 1 gallon, and the unit of filtering material as 1 cubic yard.

Thus, to express the number of units of purification effected by a filter, we have deducted the number of parts by weight of oxygen taken up by 100,000 parts of the effluent from the filter, from the number of parts by weight of oxygen taken up by 100,000 parts of the liquor going on to the filter. The figure so obtained has been multiplied by the number of gallons of liquor, per cube yard, passing through the filter in 24 hours.

179. In his Memorandum* on the measurement of the strength of sewage, Dr. McGowan has set out reasons for adopting a formula, by which the figure representing the number of parts of oxygen which the sewage will take up can be calculated, with a fair degree of accuracy.

For the purpose of ascertaining the number of parts of oxygen which an effluent will take up, Dr. McGowan has also suggested that, in lieu of carrying out the actual experiment of keeping an effluent until it has become completely oxidized, and actually measuring the amount of oxygen taken up, the amount may be approximately arrived at by a calculation based on other figures of analysis. The formula which he suggests is:

(*Ammoniacal N.* + *Organic N.*) × 4·5 + *Volatile matter of suspended solids* × 2 − Nitric Nitrogen × 3.

As regards this formula, it is well known that the better an effluent is oxidized, the less change will it undergo on keeping. The work of Dr. Adeney and others has shown that, in the case of good effluents, the figure for organic nitrogen would represent, for the most part, organic matter which had undergone fermentation, and in considering the *quality* of such effluents, e.g., with reference to their effect on streams, we think the figure may generally be neglected.

It is, however, open to question whether, in calculating the work done by a filter, it is not better to include the figure inasmuch as the whole of the organic nitrogen of liquor going on to the filter has been taken into account in calculating, by the empirical formula given on page 16, the strength or oxidizability of that liquor.

The point is further discussed in the report by Dr. McGowan and Mr. Colin Frye on the estimation of work done by filters which is contained in Appendix IV.

Until the calculation method has been compared with the results of direct experiment in a large number of cases, no precise statement as to its value can be made, but we have found it convenient to adopt it in the preparation of this Report.

On this basis the following table has been compiled showing the units of purification effected by the filters at the places indicated.

* Appendix IV.

TABLE SHOWING THE UNITS OF PURIFICATION EFFECTED BY FILTERS.

Place.	Process of Treatment.	Character of Filtering Material.	Amount treated per cube yard of filter per day.	Strength * of Liquor Treated (calculated).	* Strength ‡ of Filter Effluent (calculated).	General Quality of Effluent, as described by Dr. McGowan.	Units of Purification.
			Gallons.	Parts per 100,000	Parts per 100,000		
Chorley	Chemical precipitation and percolating filters	Very fine to coarse	500	50	0·9	Good	24,550§
Rochdale	Septic tank and percolating filters	Coarse	141	83	4·4	Good	11,125
Dorking (Experimental Works)	Chemical precipitation and percolating filters	"	211	55·3	3·9	Very fair	10,845
Kingston-upon-Thames	Chemical precipitation and single contact beds	Medium to coarse	250	51	7·7	Good	10,825
York	Septic tank and percolating filters	Coarse	150	58	−3·5‡	Good, apart from solids	9,225
Accrington	" " "	"	140	94	28·4	Good, apart from solids	9,184
Dorking (Experimental Works)	Chemical precipitation and percolating filters	"	175	53·5	3·5	Very fair	9,065
"	Settlement tank and percolating filters	"	120	80·1	8·8	Fair	8,556
"	Septic tank and percolating filter	"	120	81·6	11·2	Moderate	8,448
Normanton	Chemical precipitation and percolating filters	Very fine to coarse	98	92	10·0	Very fair	8,036
Birmingham	Septic tank and percolating filter	Medium to coarse	82½	113	20·2	Fair to good	7,656
Hampton	Triple contact beds	1st bed, coarse; 2nd bed, medium; 3rd bed, fine	43	172	−3·7‡	Good	7,555
Halton	Settlement tanks and double contact beds	Coarse	106	80	10·8	Indifferent	7,335
Hartley Wintney	Septic tank and percolating filter	Medium to fine	73	108	8·5	Moderate	7,264
Manchester	" " "	Medium	77	106	15·0	Rather poor	7,007
Huddersfield	Septic tank and single contact beds	Coarse	110	77·1	16·4	Good, apart from solids	6,897
Dorking (Experimental Works)	Chemical precipitation and percolating filter	"	120	68·8	18·1	Not very good	6,084
Hartley Wintney	Septic tanks and single contact beds	Medium to fine	73	108	27·3	Poor	5,871
Huddersfield	Septic tank and double contact beds	1st, coarse; 2nd, medium	76	77·1	3·1	Fair to good	5,624
Calverley	Chemical precipitation and single contact beds	Coarse to fine	60	124	33·2	Poor	5,448
Rochdale	Chemical precipitation and percolating filter	Coarse	157	39	5·7	Good, apart from solids	5,228
Guildford	Septic tank and percolating filter	"	50	109·2	4·8	Good	5,220

Heywood	Chemical precipitation and single contact beds	Very fine to coarse	173	40·2	11·0	Evidently not very good	5,052
Caterham	Septic tank and percolating filter	Medium to coarse	31	161	14·0	Fair	4,557
Withnell	Chemical precipitation and percolating filters	Very fine to coarse	63½	81	9·3	Very fair	4,553
Andover	Septic tank and single contact bed	Medium to fine	115	90	50·5	Poor	4,543
Horfield	Chemical precipitation and percolating filter	Coarse	151	36	6·0	Very fair to good	4,530
Leeds	Percolating filter (Leeds filter)	Very coarse	52	123	36·7	Fair	4,488
"	" " (Ducat)	Medium	25	172·6	2·3	Very good	4,373
"	Septic tank and percolating filter	Coarse	63	75·8	7·2	Good, apart from solids	4,322
"	Septic tank and double contact bed	1st, fine to medium; 2nd, medium	45	92·4	−3·1‡	Good	4,298
Guildford	Septic tank and percolating filter	Coarse	50	90·3	4·8	Good	4,275
Leeds	Double contact beds	1st, coarse; 2nd, medium	32	127	5·2	Moderate	3,998
Hendon	Percolating filter (Ducat)	Medium	40	107	7·9	Good, when settled	3,964
Maidstone	Double contact beds	1st beds, coarse; 2nd beds, fine	23·7	164	4·7	Moderate to fair	3,775
Exeter (Main Works)	Septic tank and single contact beds	Medium to coarse	55	99	31·2	Poor	3,729
Oswestry	Double contact beds	1st, medium to coarse; 2nd, medium	41	91	4·7	Fair	3,538
Sheffield	" " "	Medium to fine	60	57·6	5·1	Good	3,150
Burnley	Septic tank and double contact beds	1st, coarse; 2nd, fine	40	74·1	−1·0‡	Good	3,004
Withnell	Double contact beds	1st, coarse; 2nd, medium	18·2	174	25·3	Not satisfactory	2,706
Exeter (St. Leonard's)	Septic tank and single contact beds	Medium to fine	75	39	3·0	Fair	2,700
Guildford	Septic tank and double contact beds	1st, medium to coarse; 2nd, medium to fine	22·7	125	6·2	Moderate	2,697
Leeds	Settlement tank and percolating filter	Coarse	63	59·7	16·9	Good, apart from solids	2,696
"	Chemical precipitation and percolating filter	"	50	51·8	−0·4‡	Good to very good	2,610
Oldham	Single contact beds	Medium to fine	73	51·1	15·7	Moderate	2,584
Little Drayton	Settlement tank and percolating filter	Medium	15·2	165	6·4	Good to fair	2,411
Withnell	Chemical precipitation and percolating filter	Very fine to coarse	63½	29·8	0	Good	1,892
Clifton	Settlement tank and percolating filter	" "	15·6	123	5·8	Good to fair	1,828
Slaithwaite	Septic tank and single contact bed	Medium to coarse	62	35·6	6·3	Indifferent	1,817
Prestolee	Septic tank and percolating filter	Fine to coarse	46	22	0	*Very* good	1,012

* The strength of the liquor and filter effluent is expressed by the amount of oxygen required for the complete oxidization of its ammonia and organic matter. ‡ The minus sign which is placed against the figure representing the strength of certain effluents indicates that the oxygen present, in the form of nitrate, was, to the extent of the figure against which it is placed, more than sufficient to oxidize the organic matter in the effluent. § This figure is based on a volume of 500 gallons per cube yard per day—the actual rate at the time when the average samples were drawn. Probably about 400 gallons per cube yard per day is as much as the filters could continuously treat, and, on this basis, the number of units of purification would be rather under 20,000.

Accrington Experiments.

180. For the purpose of making an accurate comparison of the working power of contact beds and percolating filters treating the same sewage liquor, and also for comparing the treatment of strong and dilute tank liquors on each form of filter, we constructed an experimental plant at the Accrington Sewage Works.

The plant consisted of two pairs of exactly similar contact beds, 3 feet deep, and two exactly similar percolating filters, of rather coarse material, each 6 feet deep.

The cubic contents of each percolating filter was equal to that of each pair of contact beds.

The details of these experiments are set out in a Memorandum by Dr. McGowan and Mr. Colin Frye, contained in Appendix IV.

The experiments were carried out with great care, both on the spot and in the laboratory, and the results may be regarded as quantitative comparative results, from which we think useful generalisations may be drawn.

For the construction of the filters we are greatly indebted to Mr. W. J. Newton, the Surveyor to the Accrington and Church Sewage Board, while Mr. J. Boothman, the Chemist in charge at the outfall works, has controlled their daily working. The delicate adjustment of the dilutions of the tank liquor, upon which the whole value of the experiments depends, has been carried out by Mr. Boothman with the greatest care and skill, and with consistent success.

The liquor treated throughout has been the Accrington septic tank liquor, either by itself or diluted with water.

Our intention had been to treat at the same rate on the percolating filters and the contact beds, but as will be seen, it was not practicable to do this.

181. There were five experiments in all, as follows :—

Experiment I.—Comparative treatment on percolating filters and contact beds of (*a*) 100 gallons per cube yard per 24 hours of septic tank liquor and (*b*) 100 gallons of septic tank liquor + 100 gallons of water = 200 gallons of weak liquor.

The *actual average* rates of filtration on the two pairs of contact beds were 72·2 and 148·8 gallons per cube yard per day, respectively, the beds treating strong liquor being filled twice a day and those treating weak liquor four times a day. Broadly speaking, therefore, the contact beds only treated in this experiment three-fourths of the volumes treated by the percolating filters. This was owing partly to the original water capacity being less than 100 gallons per cube yard, and partly to their gradual loss of capacity. At the commencement of the experiment two fillings per day on the pair of contact beds treating strong liquor were equivalent to 90 gallons per cube yard, and four fillings per day on the pair treating weak liquor were equivalent to 179 gallons.

Duration of experiment :—May 5th, 1905, to June 30th, 1906.

Experiment II.—Comparative treatment on percolating filters and contact beds of (*a*) 100 gallons per cube yard per 24 hours of septic tank liquor and (*b*) of 50 gallons of septic tank liquor + 50 gallons of water = 100 gallons of weak liquor.

The *actual average* rates on the contact beds were 51·6 and 57·9 gallons per cube yard per day, respectively.

Duration of experiment : July 2nd, 1906, to March 23rd, 1907.

Experiment III.—Comparative treatment on percolating filters *alone* of (*a*) 125 gallons per cube yard per 24 hours of septic tank liquor and (*b*) 125 gallons of septic tank liquor + 125 gallons of water = 250 gallons of weak liquor.

Duration of experiment :—April 8th to June 7th, 1907.

Experiment IV.—Comparative treatment on percolating filters alone of (*a*) 200 gallons per cube yard per 24 hours of septic tank liquor; and (*b*) 200 gallons of septic tank liquor + 200 gallons of water = 400 gallons of weak liquor.

Duration of experiment :—June 10th to October 26th, 1907.

Experiment V.—Comparative treatment on percolating filters alone of (*a*) 250 gallons per cube yard per 24 hours of septic tank liquor; and (*b*) 250 gallons of septic tank liquor + 250 gallons of water = 500 gallons of weak liquor.

Duration of experiment :—October 28th, 1907, to June 18th, 1908.

The main object of these last three experiments, besides the further comparison between the purification of the two liquors, was to see how much these filters can actually treat, with the production of a good effluent.

The following is a general summary of the results of these experiments :—

182. *Accrington Experiment I.*—The percolating filters of coarse material effected practically the same amount of purification, whether they were treating 100 gallons per cube yard of undiluted septic tank liquor, or 200 gallons per cube yard of a liquor of half the strength, the total organic impurity going on to the filters being the same in both cases.

The primary contact bed, when the pair of beds were treating about 150 gallons of weak liquor per cube yard per day, gave rather better results than the primary bed of the pair treating strong liquor at half this rate, and the same is true, in each case, of the secondary beds. So long, therefore, as care is taken to avoid water-logging, *i.e.*, to give the beds sufficient time to drain and aerate, it is rather easier to treat upon contact beds two volumes of weak liquor than one volume of strong liquor.

During the fourteen months over which this experiment extended, the percolating filters treating strong liquor did one and a half times as much work as the contact beds treating strong liquor, while the percolating filters treating weak liquor did one and a third times as much work as the contact beds treating weak liquor.

The units* of purification were as follows :—

	Units of Purification per cube yard.
Percolating filter treating strong tank liquor	7,310
Double contact beds treating strong tank liquor	5,011
Percolating filter treating weak tank liquor	7,678
Double contact beds treating weak tank liquor	5,803

As regards the quality of the two strong liquor effluents, *suspended solids included*, the results were slightly in favour of the percolating filter effluent, which still required 12 parts of oxygen per 100,000 for its complete oxidation, while the contact bed effluent required 16 parts. If we *eliminate the solids* in both cases, the oxidizability of the liquid alone would be approximately represented by 2 parts of oxygen in the case of the percolating filter effluent, and 8 parts in the case of the contact bed effluent. This superiority of the percolating filter effluent, so far as lesser oxidizability is concerned, was partly due to the fact that it contained 2·4 parts of nitric (plus nitrous) nitrogen, as against 1 part in the contact bed effluent; but even apart from this, it was rather the better, the actual oxidizable matter left in the liquid being equivalent to about 8·5 parts of oxygen, while that in the contact bed effluent was equivalent to about 10 parts.

In the case of the two weak liquor effluents, suspended solids included, the results were in favour of the double contact bed effluent, which only required 4 parts of oxygen for its complete oxidation, as against 9·5 parts for the percolating filter effluent. If we eliminate the solids, there was practically no difference in the quality of the two effluents, both of them being well oxidized. If both solids and nitrate are eliminated, the double contact bed effluent is again rather the better, with an oxidizability figure of 4, as against 6·5 for the percolating filter effluent.

The above figures may be tabulated as follows :—

	Effluents from Strong Tank Liquor.		Effluents from Weak Tank Liquor.	
	Percolation.	Double Contact.	Percolation.	Double Contact.
† Oxidizability of whole effluent, including solids and giving credit for nitrate	*Parts of* 12	*oxygen per* 16	100,000 *parts* 9·5	*of effluent.* 4·0
Oxidizability of effluent, without its suspended solids, and giving credit for nitrate	2	8	2·0	2·0 ap.
Oxidizability of effluent, without solids, and giving no credit for nitrate	8·5	10	6·5	4·0

* The units of purification are calculated on the basis indicated on page 107 of this Report.

† Oxidizability calculated on the formula suggested by Dr. McGowan (*see* paragraph 179, page 107).

The quality of the effluents *without their suspended solids*, as regards taking up of dissolved oxygen in 24 hours and incubation, is shown by the following figures:—

Parts per 100,000.

	Effluents from Strong Tank Liquor.		Effluents from Weak Tank Liquor.	
	Percolation.	Double Contact.	Percolation.	Double Contact.
Dissolved oxygen taken up from water in 24 hours at about 18° C. (65° F.)	0·30 (22) 0·37 (12)	0·61 (11)	0·28 (21) 0·30 (11)	0·31 (10)
Incubation (by smell)	All passed (25).	All passed (11).	All passed (21).	All passed (10).

Figures in brackets represent number of estimations.

183. *Accrington Experiment II.*—In the comparative treatment, *upon the percolating filters of coarse material*, of 100 gallons of strong and 100 gallons of weak tank liquor, respectively, nothing was gained in purity of effluent by giving the filter treating the weak liquor only half the work to do; this filter was merely working much under its real power.

It was noteworthy that in Experiments I. and II. the actual efficiency of the contact beds (treating both strong and weak tank liquor), as regards work done per cube yard, remained the same throughout. In both experiments about two-thirds of the impurity of the septic tank liquor was removed by the primary bed, whether strong or weak liquor was being treated.

In Experiment II., which lasted for eight months, the percolating filter treating 100 gallons per cube yard of strong liquor did more than twice as much actual work as the double contact beds treating 51·6 gallons with two fillings per day; the reason for this increasing difference in work done, as compared with Experiment I., was the gradual loss of capacity in the contact beds.

The units of purification in Experiment II. were as follows:—

	Units of Purification per cube yard.
Percolating filter treating strong tank liquor	8,440
Double contact beds treating strong tank liquor	3,576
Percolating filter treating weak tank liquor	4,120
Double contact beds treating weak tank liquor	2,200

The quality of the effluents was as follows:—

	Effluents from Strong Tank Liquor.		Effluents from Weak Tank Liquor.	
	Percolation.	Double Contact.	Percolation.	Double Contact.
	Parts of oxygen per 100,000 parts of effluent.			
Oxidizability of whole effluent including solids, and giving credit for nitrate	−3·2	14·0	−0·7	4·2
Oxidizability of effluent, without its suspended solids and giving credit for nitrate	−6·2	5·8	−3·3	0·2
Oxidizability of effluent, without solids and giving no credit for nitrate	3·6	7·7	2·4	3·2

NOTE.—The minus sign indicates that the oxygen present, in the form of nitrate, was, to the extent of the figure against which it is placed, more than sufficient to oxidize the organic matter in the effluent.

The quality of the effluents—*without their suspended solids*—as regards taking up of dissolved oxygen and incubation, is shown by the following figures:—

	Effluents from Strong Tank Liquor.		Effluents from Weak Tank Liquor.	
	Percolation.	Double Contact.	Percolation.	Double Contact.
	Parts per 100,000.			
Dissolved oxygen taken up from water in 24 hours at about 18° C.	0·03 (4)	0·12 (4)	0·07 (4)	0·10 (4)
Dissolved oxygen taken up from water in 5 or 6 days	0·43 (3)	1·70 (3)	0·33 (4)	1·0 ap. (3)
Incubation (by smell)	All passed (8)	All passed (8)	All passed (8)	All passed (8)

The capacities of the contact beds were as follows:—

	At beginning of Experiment, July 2nd, 1906.	At end of Experiment, February 18th, 1907.	Loss of capacity in Gallons.	Percentage loss of water capacity.
	gallons.	gallons.		
Primary bed treating strong tank liquor	735	640	95	8 per cent.
Secondary bed treating strong tank liquor	1,030	970	60	6 "
Primary bed treating weak tank liquor	780	750	30	3 "
Secondary bed treating weak tank liquor	950	890	60	6 "

As already stated, the actual volumes of liquid treated per cube yard per twenty-four hours throughout Experiment II. were:—

Percolating filter treating strong tank liquor - 100 gallons.
Double contact beds treating strong tank liquor - 51·6 "
Percolating filter treating weak tank liquor - 100 "
Double contact beds treating weak tank liquor - 57·9 "

The contact beds thus treated only about half as much liquor, in both cases, as the percolating filters.

184. *Accrington Experiment III.*—In this experiment, which lasted from April 8th to June 7th, 1907, the percolating filter treating strong liquor received 125 gallons per cube yard per day and that receiving weak liquor 250 gallons per cube yard per day. It was thus similar to Experiment I, but with an increased dose in the case of both filters, the object being to see how much the filters could actually treat with efficiency. Owing to the wet season, however, the strength of the liquors in this last experiment was less than in Experiments I and II, thus:—

	Calculated Strength.	Suspended Solids.
Strong tank liquor	73·2	20·1
Weak tank liquor	40·7	10·3

The suspended solids in the filter effluents were rather high, on account of the "spring out-flush." *

The purification obtained was as follows:—

	Units of Purification per cube yard.
Percolating filter treating strong tank liquor	8,050
Percolating filter treating weak tank liquor	9,225

* As is now well known, large quantities of suspended solids usually come out in the effluent from a percolating filter of coarse material in the late spring, with the advent of the warmer weather. This appears to be due to the development of worms, larvæ, etc., in the interior of the filter at this time. The same thing has been observed, though in lesser degree, in the case of percolating filters of fine material and also contact beds.

The quality of the two effluents is shown by the following figures :—

	Effluents from Strong Tank Liquor.	Effluents from Weak Tank Liquor.
	Parts of oxygen per 100,000 parts of effluent.	
Oxidizability of whole effluent, including solids and giving credit for nitrate.	8·8	3·8
Oxidizability of effluent, without its suspended solids and giving credit for nitrate.	– 2·2*	– 1·4*
Oxidizability of effluent, without solids and giving no credit for nitrate.	4·8	2·7

The quality of the effluents—*without their suspended solids*, as regards taking up of dissolved oxygen and incubation—is shown by the following figures :—

	Effluent from Strong Tank Liquor.	Effluent from Weak Tank Liquor.
Dissolved oxygen taken up from water in 5 days at 18° C.	0·62 (5)	0·84 (5)
Incubation (by smell)	All passed (5)	All passed (5)

Both effluents were therefore very good, and, apart from their suspended solids, there was practically nothing to choose between them. It will be noted that the filter treating weak liquor was receiving a liquor a little more than half as strong as the other (calculated strength—40·7, as against 73·2 for the strong liquor).

Owing to the strong liquor being less concentrated in this experiment than in the two preceding ones, the actual work done on the filter treating strong liquor was only 8,050 units per cube yard per 24 hours, but in the case of the filter treating weak liquor it was 9,225 units.

185. *Accrington Experiment IV.*—In this experiment, which lasted from June 10th to October 26th, 1907, the percolating filter treating strong liquor received 200 gallons per cube yard per day, and that receiving weak liquor 400 gallons per cube yard per day. It was thus similar to Experiments I. and III., but with a further increased dose in the case of both filters. The calculated strengths of the tank liquors in this experiment were almost the same as in the preceding one, but the suspended solids were less in amount, thus :—

	Calculated Strength.	Suspended Solids.
Strong tank liquor	74·1	13·5
Weak tank liquor	39·6	6·3

The weak liquor filter was again treating a liquor which was *rather more* than half as strong as the other.

The purification obtained was as follows :—

	Units of Purification per Cube Yard.
Percolating filter treating strong tank liquor	14,300
Percolating filter treating weak tank liquor	15,160

The quality of the two effluents is shown by the following figures :—

	Effluents from Strong Tank Liquor.	Effluents from Weak Tank Liquor.
	Parts of oxygen per 100,000 parts of effluent.	
Oxidizability of whole effluent, including solids and giving credit for nitrate	2·6	1·7
Oxidizability of effluent, without its suspended solids and giving credit for nitrate	– 3·8*	– 3·1*
Oxidizability of effluent, without solids and giving no credit for nitrate	4·4	2·3

* The minus sign indicates that the oxygen present, in the form of nitrate, was, to the extent of the figure against which it is placed, more than sufficient to oxidize the organic matter in the effluent.

The quality of the effluents—*without their suspended solids*, as regards taking up of dissolved oxygen and incubation—is shown by the following figures :—

	Effluent from Strong Tank Liquor.	Effluent from Weak Tank Liquor.
Dissolved oxygen taken up from water in five days at 18°C.	0·56 (9)	0·49 (9)
Incubation (by smell)	All passed (9)	All passed (9)

Here, again, both effluents were well oxidized and good, and there was little to choose between them. If anything, they were rather better oxidized than the corresponding effluents in Experiment III. (notwithstanding the lesser volumes treated in that case), as judged by the dissolved oxygen taken up by the paper-filtered effluents in five days. This was probably due to the fact that more of the warm summer months were included in Experiment IV.; and that the spring out-flush of solids took place during Experiment III.

The work done on the filter treating strong liquor was 14,300 units, and on the filter treating weak liquor 15,160 units.

186. *Accrington Experiment V.*—In this final experiment, which lasted from October 28th, 1907, to June 18th, 1908, the percolating filter treating strong liquor received 250 gallons per cube yard per day, and that receiving weak liquor 500 gallons per cube yard per day. The calculated strengths of the liquors treated were a little less than in Experiment IV., though suspended solids were present in rather larger amount, thus :—

	Calculated Strength.	Suspended Solids.
Strong tank liquor	69·4	14·4
Weak tank liquor	37·0	7·4

As before, the weak liquor filter was treating a liquor which was fully half as strong as the other.

The purification obtained was as follows :—

	Units of Purification per cube yard.
Percolating filter treating strong tank liquor	12,425
Percolating filter treating weak tank liquor	14,600

The quality of the two effluents is shown by the following figures :—

	Effluents from Strong Tank Liquor.	Effluents from Weak Tank Liquor.
	Parts of oxygen per 100,000 parts of effluent.	
Oxidizability of whole effluent, including solids and giving credit for nitrate	19·7	7·8
Oxidizability of effluent, without its suspended solids and giving credit for nitrate	7·1	2·2
Oxidizability of effluent, without solids and giving no credit for nitrate	10·8	5·0

The quality of the effluents—*without their suspended solids*, as regards taking up of dissolved oxygen and incubation—is shown by the following figures :—

	Effluent from Strong Tank Liquor.	Effluent from Weak Tank Liquor.
Dissolved oxygen taken up from water in five days at 18°C.	2·31 (13)	1·16 (13)
Incubation (by smell)	11 passed, 2 failed (13)	All passed (13)

The effluents in Experiment V. thus show a marked falling off in quality as compared with those in Experiments IV. and III. Leaving suspended solids out of account, the weak liquor effluent is distinctly better, relatively, than the effluent from the strong liquor. It will be noted, however, that even in this last experiment, after filtration through paper, only two of the thirteen strong liquor effluents failed on incubation, while all thirteen weak liquor effluents passed that test. The latter effluents might be described as fairly good, but the strong liquor effluents as rather poor. The spring outflush of solids again took place during this experiment, which—it must be borne in mind—was carried out for the most part in the coldest months of the year.

The work done on the filter treating strong liquor was 12,425 units and on the filter treating weak liquor 14,600 units.

It was evident, from the appearance of the filters during the progress of Experiment V., that they were being overtaxed, especially the strong liquor filter. The concrete at the base of the filters gradually became blackened and covered, more or less, with grey fungus, while at times the effluents smelt slightly of sewage.

187. Reviewing shortly the foregoing five experiments, we think that they may be taken to show that percolating filters of coarse material, 6 feet deep, can treat a strong septic tank liquor (strength 73 to 85) at a rate of 100 to 125 gallons per cube yard per day, or a liquor of half this strength at the rate of 200 to 250 gallons, giving from 8,000 to 9,000 units of purification, and producing at the same time a good effluent (apart from suspended solids).

Under favourable conditions of summer weather, a strong septic tank liquor (strength 74) can be treated at a rate up to 200 gallons per cube yard per day, or a liquor of half this strength at a rate up to 400 gallons per day, with from 14,000 to 15,000 units of purification and the production of a good effluent. This, we think, is probably the maximum work which can be expected from percolating filters of coarse material treating ordinary septic tank liquor at a regular rate of flow.

As regards the question whether it is easier to treat upon percolating filters of coarse material one volume of strong septic liquor or two volumes of weak, the organic impurity being the same in both cases, there is little difference either in the actual work done by the filters or in the quality of the effluents, at rates of working up to 200 and 400 gallons per cube yard per day. If any distinction is to be drawn, the advantage lies with the filter treating the weaker liquor, no doubt because the natural aeration of the extra volume of liquid rather more than counterbalances the quicker rate of flow through the filter.

Apart from complications arising from the presence of large quantities of suspended solids (*cf.* pp. 48 *et. seq.*), we think that the above statement with regard to the purification of strong and weak septic-tank liquors may be taken to apply also to settled sewage and precipitation liquor.

Double contact beds will, during their first year of work, at the rate of two fillings per day, treat 70 gallons of strong or 150 gallons of weak tank liquor per cube yard per day, with 5,000 to 6,000 units of purification for the first year. Their working power will, however, gradually fall off as the beds lose capacity. Here, again, it is rather easier to treat two volumes of weak than one volume of strong liquor.

It is clear from these experiments that, other things being equal, a greater purification per cube yard, as measured by the actual *amount* of oxygen used up, is effected when the final product is an *imperfectly* oxidized effluent. The indications are that, unit for unit, the first or carbon stage of the oxidation is, under the conditions of filtration, easier, or at least quicker, and therefore presumably requires less expenditure of energy than the second or nitrification stage. We may perhaps be able to make some further experiments with these filters, to clear up this point.

At the end of this section (*see* p. 121) we print in a summarized form tables of the results from a large number of places, most of which have been under our own observation.

General Conclusions as to the Working Power of Different Types of Filter.

188.—*Treatment of Crude or Partially Settled Sewage upon Double Contact Beds.*

The volume of sewage which can be treated by double contact, so as to give a fair or good effluent, varies almost inversely as the "strength," *e.g.*, 24 gallons per cube yard per day of sewage with a strength of 164, or 58 gallons of sewage with a strength of 60. During the "economic life" of the beds, an average of 3,000 to 4,000 units of purification per cube yard of filter per day may be looked for in the treatment of crude or settled sewage upon primary beds of coarse material and secondary beds of fine material, an effluent of fair to good quality being produced.

Treatment of Crude or Partially Settled Sewage on Percolating Filters.

Broadly speaking, the volume of sewage which can be treated upon percolating filters, with the production of a good effluent, depends mainly upon its strength, especially if no complications ensue through the choking of the filter and if the filter is working up to its full power. Twenty to 25 gallons per cube yard per day of a sewage having a strength of about 170, or 60 gallons of sewage with a strength of 60, can be successfully dealt with upon filters of medium to coarse material, 2,500 to 3,500 units of purification being obtained. When the sewage is *well settled*, about 100 to 120 gallons of such sewage with a strength of about 80, can be filtered per cube yard per day, and 7,000 to 8,000 units of purification, or probably even more than this,† obtained. In this case, therefore, the process is comparable with the treatment of septic liquor upon percolation filters.

Treatment of Septic Tank Liquor on Single Contact Beds.

The volume of septic tank liquor which can be treated by single contact varies almost inversely as the strength of the liquor. Single beds of medium to coarse or medium to fine material, may be expected to give from 3,000 to 4,500 units of purification, when dealing with either strong or weak liquors. If the tank liquor is a weak one, and if the material of the bed is fine, this purification will be sufficient to yield a good or fairly good effluent, but not otherwise. A weak liquor, of strength 30 to 50, and containing up to 6 or 8 parts of suspended solids, can in this way be successfully treated at the rate of 100 to 150 gallons per cube yard per day. As a rule, however, septic tank liquors are too strong to allow of one contact being sufficient to give a good effluent.

Treatment of Septic Tank Liquor on Double Contact Beds.

The volume of septic tank liquor which can be treated by double contact varies almost inversely as the strength. Where the *primary* beds are of medium to fine material a strong liquor of strength 90 may be treated by double contact at the rate of 50 gallons per cube yard per day ; a liquor of strength 70 at the rate of 70 gallons ; and a weak liquor of strength 40 at the rate of 100 gallons. From 3,500 to 4,500 units of purification may be expected here, with the production of good effluents.

Treatment of Septic Tank Liquor on Percolating Filters.

The volume of septic tank liquor which can be treated upon percolating filters varies more or less inversely as the strength. A percolating filter of coarse or of medium to coarse material, and from 6 to 9 feet in depth, may be expected to give from 7,000 to

† *Cf.* Appendix IV., Report to the Commission on the Dorking Experimental Installation, by E. H. Richards (1907).

11,000 units of purification when treating either strong or weak tank liquors, and to yield good effluents. This would correspond to 80 gallons per cube yard of a strong liquor of strength 113, or 150 gallons of a weak liquor of strength 58. The less coarse the material, provided that it can allow the free passage of effluent suspended solids through it, the greater is the relative purification per cube yard.

Treatment of Precipitation Liquor on Single Contact Beds.

Our data with regard to this process are rather few, but they indicate clearly that—as in the case of settled sewage and septic tank liquor—single contact of precipitation liquor from strong sewages is not sufficient to produce a good effluent. The better clarified the liquor, the more of it can be treated. The very well clarified liquor at Kingston-on-Thames, with a strength of about 50, was treated for over six years upon an experimental coke bed of medium to coarse material, 3 feet deep, at a rate of 250 gallons per cube yard per day (four fillings), giving 10,800 units of purification and producing a fair to good effluent. A more dilute tank liquor, equally well clarified, might be treated in even larger volume than this, so far as the "strength" was concerned, but it is doubtful whether more than four fillings per day would be practicable on a large scale for any length of time.

Treatment of Precipitation Liquor on Double Contact Beds.

We have had no actual experience of this process, which would be applicable to precipitation liquors from strong sewages. We should not expect, however, to obtain such a high figure for units of purification as in the treatment of medium or weak liquor by single contact. Probably about 6,000 to 7,000 units would be the maximum obtainable. This would correspond to about two to two and-a-half fillings per day of a liquor of strength 100 or about three to three and-a-half fillings of a liquor of strength 75.

Treatment of Precipitation Liquor on Percolating Filters.

In this case it cannot be said that the volume of precipitation liquor treated per cube yard of filter at the different places under observation varied inversely as the strength. The main reason for this is that suspended solids can be reduced in most precipitation liquors to a very low figure, in which case very fine material may be used for the filtration of large volumes. At the places which were under observation the filtering material varied greatly in size and the liquors contained very different quantities of suspended solids. Nevertheless with material of a given size, strength and volume would, no doubt, bear an inverse relation to one another. From the results obtained with percolating filters, of coarse and fine material, respectively, we have arrived at the following broad conclusions :—

(*a*) The volume of precipitation liquor which can be treated upon filters of *coarse* material depends mainly upon the strength of the liquor.

(*b*) The volume which can be treated upon filters of *fine* material depends not merely upon the strength, but also to a marked extent upon the degree of clarification of the liquor.

Upon deep filters of coarse material, about 150 gallons of precipitation liquor of about average strength (strength 50 to 60) or 200 to 250 gallons of weak liquor (strength 30 to 40) can be treated per cube yard per day, yielding up to about 8,000 units of purification, and producing a good effluent. In the case of very strong liquors the volume would probably have to be *more than* proportionately reduced.

Upon shallow filters of fine material a *clear* liquor with a strength of 50 can be treated at the rate of 300 to 400 gallons per cube yard per day, giving about 18,000 units of purification, and producing a very fair to good effluent. It has to be borne in mind, however, that filters of very fine material working at this rate have to be constantly washed and scraped. About 500 gallons per cube yard per day would probably be the largest volume of any liquor, however weak, that could be treated on such filters regularly, day by day.

The rates of treatment which are given in the foregoing paragraphs could generally be doubled in times of storm.

Summary.

189. The following tables gives an *approximate* idea of the purification which can be effected by different kinds of filter treating different liquors, so as to produce a fair to good effluent :—

	Units of Purification per cube yard :—
Crude or partially settled sewage treated on double contact beds	3,000 to 4,000
Crude or partially settled sewage treated on percolating filters	2,500 to 3,500
Well settled sewage treated on percolating filters	7,000 to 8,000, and probably up to 11,000
Septic tank liquor treated on single contact beds	3,000 to 4,500
Septic tank liquor treated on double contact beds	3,500 to 4,500
Septic tank liquor treated on percolating filters	7,000 to 11,000
Precipitation liquor treated on single contact beds	Up to 11,000
Precipitation liquor treated on double contact beds	*Probably* up to 6,000 to 7,000
Precipitation liquor treated on percolating filters :—	
(*a*) Filters of coarse material	Up to about 8,000
(*b*) Filters of fine material	Up to about 18,000

GENERAL SUMMARY AS TO CONTACT BEDS AND PERCOLATING FILTERS.

190. (1)—The amount of sewage which can be purified per cube yard of contact bed or percolating filter varies—within practical limits—nearly inversely as the strength of the liquor treated. This statement is based on the assumption that the size of the material of which the filter is composed is, in each case, suitable to the character of the liquor treated, and that the material is arranged at the proper depth to secure maximum efficiency (*see* Paragraph 153, p. 87).

(2) Taking into account the gradual loss of capacity of contact beds, a cubic yard of material arranged in the form of a percolating filter will generally treat satisfactorily nearly twice as much tank liquor as a cubic yard of material in a contact bed.

(3) In the case of sewage containing substances which have an inhibitory effect upon the activity of micro-organisms, the working power per cube yard of filter of either type may be more nearly equal. This point, however, is not clearly established.

(4) Percolating filters are better adapted to variations of flow than contact beds.

(5) The effluents from percolating filters are usually much better aerated than the effluents from contact beds, and apart from suspended solids, are of a more uniform character. On emptying a contact bed, the first flush is usually much more impure than the average effluent from the bed.

(6) The risk of nuisance from smell is greater with percolating filters than with contact beds.

(7) It is also found that with percolating filters, there is nuisance from flies, especially with filters constructed of coarse material. In the warmer months of the year, such filters swarm with members of the *Psychodidae*, which, though appearing to breed and develop in the filters, may usually be seen in large numbers on the walls of houses and buildings close to or on the works. At Accrington and Dorking a small midge-like fly with a dark body and striped wings has appeared and causes inconvenience to the men by its bite, which gives rise to local irritation.

TABLES OF ANALYTICAL RESULTS OBTAINED: (*a*) AT THE DIFFERENT SEWAGE WORKS WHICH HAVE BEEN UNDER OBSERVATION BY OUR OWN OFFICERS; (*b*) BY THE AUTHORITIES AT THE SEWAGE WORKS OF BIRMINGHAM, BURNLEY, HEYWOOD, HUDDERSFIELD, LEEDS, MANCHESTER, OLDHAM, AND SHEFFIELD.

Prefatory Note to Tables.

191. The figures of analysis given for crude and settled sewage, septic tank liquor, and precipitation liquor, refer to the *hourly* sets of samples only in the case of the works which have been under observation by our own officers, these hourly sets representing as far as possible the dry weather flow. For purposes of comparison, we have given the average figures for the *hourly* sets of effluent samples (*i.e.*, dry weather samples), and the average figures for the ordinary *chance* samples of effluent. There were, as a rule, a fair number of such chance effluents examined from each place, and the figures may generally be looked upon as representing roughly the average of the effluents obtained in all weathers. In the case of the other places (Leeds, Manchester, etc.) the figures given for the sewages, tank liquors, and effluents are the averages of a very large number of *chance* samples. These latter figures were furnished by the authorities of the various sewage works mentioned, and they are printed in italics to distinguish them from our own figures.

The figures for "oxygen absorbed in four hours" given in italics were obtained with weak permanganate, and therefore require to be multiplied by 1·6, in order to make them fairly comparable with our own *four hours'* figures, which were obtained with strong permanganate.

With regard to the bacteriological notes, wherever possible, the figures given refer to the number of B. Coli (or Coli-like microbes) per c.c. In the few cases where this test was not applied, or where the records were very few in number, approximate figures are given, based upon the results obtained by the use of one or more presumptive tests for B. Coli. The results frequently varied so much that the figures can only be taken as being roughly approximate; bacteriological results obtained by the decimal method of dilution do not lend themselves readily to expression in the form of averages. Further, a good deal of latitude has been exercised in the way of pitting high results against low results and ignoring exceptional ones. We think, therefore, that the bacteriological figures given in the following tables should be read in the light of the detailed tables which are incorporated in the text of the separate reports, printed in Appendix III.

TABLE I.—ANALYSES OF CRUDE SEWAGE.

No.	Place.	Population	System of Sewerage.	Dry weather flow of Sewage (gallons).	Nature of Sewage.	Analysis of Sewage. Parts per 100,000.				B. Coli per c.c.	Preliminary Grit Settlement.	Remarks.
						Ammoniacal Nitrogen.	Albuminoid Nitrogen.	Oxygen absorbed in 4 hours.	Suspended Solids.			
1	Hampton -	6,500	Separate	180,000	Strong domestic	9·40	1·38	17·82	48·5	At least 100,000.	Partial settlement on surface of primary beds.	
2	Leeds - -	450,000	Combined	15,500,000	Trade sewage	*3·28* *2·30* *1·54*	*1·26* *0·65* *0·85*	*14·10* *10·27* *10·80*	*85·0* D. *53·3* L. *52·5* C.	About 100,000.	Partial settlement	Experimental processes. Fixed quantity treated daily; compare D with Ducat filter effluent, C with contact bed effluent, and L with "Leeds" filter effluent.
3	Maidstone -	34,000	Partially separate.	1,500,000	Domestic, with much brewery and tannery waste.	3·51	1·52	21·03	34·8	At least 100,000.	Partial settlement in pump well.	Experimental process. Fixed quantity treated daily.
4	Newton -	9,000	Combined	145,000	Domestic (mainly slop water).	4.30*	0·86*	12·32	30·6	At least 100,000.	Slight settlement in distributing troughs.	
5	Withnell -	1,650	Partially separate.	15,000	Very strong domestic	5·35	1·23	21·19	33·9	At least 100,000.	Partial settlement in grit chamber.	Experimental process. Fixed quantity treated daily.

NOTE—The figures of analysis given in ordinary type are, as a rule, averages of three sets of twenty-four hourly samples, drawn in dry weather, according to rate of flow. The figures of analysis given in italics are, as a rule, averages of a large number of chance samples, drawn in all weathers. All figures for "Oxygen absorbed in four hours" given in italics, having been obtained with "weak" permanganate, must be multiplied by 1·6 to compare approximately with the figures for "Oxygen absorbed in four hours" given in ordinary type, the latter having been obtained with "strong" permanganate.

* These numbers are inferred; they will be nearly right.

TABLE II.—SETTLEMENT OF SEWAGE WITHOUT THE AID OF CHEMICALS.

No.	Place.	Population.	System of Sewerage.	Dry weather flow of Sewage (gallons).	Nature of Sewage.	Analysis of Sewage. Parts per 100,000. Ammoniacal Nitrogen.	Albuminoid Nitrogen.	Oxygen absorbed in 4 hours.	Suspended Solids.	B. Coli per c.c.	Rate of flow through tanks (expressed in time taken to fill tank in dry weather).	Analysis of Settled Sewage. Parts per 100,000. Ammoniacal Nitrogen.	Albuminoid Nitrogen.	Oxygen absorbed in 4 hours.	Suspended Solids.	B. Coli per c.c.	Tanks Cleaned.	Method of Disposing of Sludge.	Remarks.
7	Clifton - -	2,000	Partially separate.	22,000	Strong slop-water domestic.	3·78	1·11	26·07	49·1	At least 100,000.	5·3 hours	3·96	0·76	15·13	24·2	100 to 10,000.	Every 5 weeks	Taken by farmer.	
8	Halton - -	2,000	Combined	35,000	Domestic (mainly slop-water).	4·74	*0·85	11·83	17·7	At least 100,000.	15·5 hours	4·72	*0·69	8·33	10·7		Every 7 weeks	Lagooned, taken by farmers when dry.	
9	Little Drayton -	1,550	Ditto	12,000	Strong slop water domestic.	7·57	1·41	24·44	23·9	At least 100,000.	0·93 hours	7·54	1·16	18·21	19·9		Every week	Lagooned	
10	Leeds - - -	450,000	Ditto	15,500,000	Trade sewage.	*1·92*	*0·68*	*11·34*	*58·1*	About 100,000.	4·0 hours average rate 8·0 hours	*1·60* *1·74* *1·90*	*0·37* *0·39* *0·41*	*5·24* *5·50* *5·84*	*12·8* *12·2* *11·7*			Lagooned	Experimental process.
11	Oswestry - -	9,800	Ditto	350,000	Domestic with brewery and tannery waste.	3·53	0·91	11·27	29·4	At least 100,000.	4·1 hours	3·48	0·92	10·37	22·8		Every 4 or 5 weeks.	Mixed with house ashes and taken by farmers.	
12	Sheffield - -	400,000	Ditto	14,500,000	Trade sewage.	*2·61*	*0·76*	*7·08*	*50·2*		8 hours	*2·19*	*0·41*	*4·23*	*10·7*		Every week	Lagooned	Experimental process.
13	Oldham - -	—	Ditto	2,250,000	Rather weak domestic.	*3·17*	*0·77*	*5·60*	*51·2*	About 100,000.	12 hours	*3·22*	*0·53*	*3·06*	*15·8*			Pressed and taken by farmers.	

NOTE.—The figures of analysis given in ordinary type are, as a rule, averages of three sets of twenty-four hourly samples drawn in dry weather, according to rate of flow. The figures of analysis given in italics are, as a rule, averages of a large number of chance samples drawn in all weathers. All figures for "oxygen absorbed in four hours" given in italics, having been obtained with "weak" permanganate, must be multiplied by 1·6 to compare approximately with the figures for "oxygen absorbed in four hours" given in ordinary type, the latter having been obtained with "strong" permanganate. * The figures are probably rather too high.

TABLE III.—TREATMENT OF SEWAGE IN SEPTIC TANKS.

No.	Place.	Population.	System of Sewerage.	Dry weather flow of sewage (gallons).	Nature of Sewage.	Analysis of Sewage. Parts per 100,000. Ammoniacal Nitrogen.	Albuminoid Nitrogen.	Oxygen absorbed in 4 hours.	Suspended Solids.	B. Coli per c.c.	Rate of flow through tanks (expressed in time taken to fill tank in dry weather.)	Analysis of septic tank liquor. Parts per 100,000. Ammoniacal Nitrogen.	Albuminoid Nitrogen.	Oxygen absorbed in 4 hours.	Suspended Solids.	B. Coli per c.c.	Tanks Cleaned.	Method of Disposing of Sludge.	Remarks
14	Accrington -	46,300	Combined	1,180,000	Strong domestic.	5·18	0·68	9·93	43·3	At least 100,000.	42 hours	5·03	0·34	8·67	19·4	At least 100,000.	Every 4 to 6 months.	Lagooned and sold when dried.	
15	Andover - -	5,000	Partially separate.	150,000	Domestic, with brewery waste	7·37	1·18	10·02	16·5	At least 100,000.	19·3 hours	7·44	0·98	7·53	11·1	At least 100,000.	Partial removal at short intervals.	Run into trenches and covered over.	
16	Birmingham -	865,701	Combined and partially separate.	22,000,000	Trade sewage	*3·67**	*0·98**	*20·32**	*48·4**	—	10-12 hours	*6·12* *6·67*	*0·88* *0·54*	*15·86* *12·00*	*19·5* A. *8·10* B.	—	Roughing tanks once a week. Septic tanks periodically.	*Buried in adjacent* ground.	"A" represents the septic tank liquor as a whole and "B" the same liquor after it has passed through Dortmund tanks, but also after it has received 3,000,000 gallons of domestic sewage at Tyburn.
17	Burnley - -	82,000	Ditto	2,000,000	Domestic, with trades waste.	*3·32*	*0·97*	*9·98*	—	—	15 hours	*2·54*	*0·50*	*6·33*	*5 to 6*	—	Every six months	Sludge pressed and sold to farmers.	
18	Caterham - -	1,300 (assumed.)	Separate	17,000	Very strong domestic.	13·41	1·75	17·99	42·1	At least 100,000.	—	18·48 18·09	1·06 1·38	10·15 13·89	12·6 A. 25·4 B.	About 100,000.	—	Run on to ground	Only one-third of sewage treated. The liquor represented by analysis "A" runs on to filter, while that represented by "B" runs on to land.
19	Exeter (St. Leonards).	1,500	Partially separate.	70,000	Weak domestic.	2·86†	—	4·35	13·0	At least 100,000.	17·8 hours	4·12	0·65	3·64	5·7	At least 100,000.	After 2 or more years.	Lagooned	
20	Exeter (Main works).	38,000	Combined	1,300,000	Domestic, with trades waste.	4·66	1·37	19·86	37·2	About 100,000.	11·5 hours	5·40	0·91	10·20	12·5	About 100,000.	Partial removal at short intervals.	Buried in fine clinker screenings.	
21	Guildford - -	16,000	Partially separate.	400,000	Domestic, with brewery waste.	7·39	1·91	21·96	42·1	At least 100,000.	36·7 hours	9·11	1·00	11·42	15·9	At least 100,000.	—	Buried shallow in ground.	Experimental process. Fixed quantity treated daily.
22	Hartley Wintney	1,600	Ditto	45,000	Ditto	A. 2·43 B. 7·47	0·68 1·79	14·61 18·64	20·1 32·7	At least 100,000.	31·7 hours	A. 3·13 B. —	0·73 —	13·16 —	15·1 —	About 100,000.	Partial removal at short intervals.	Run on to land	The samples for analysis series "A" were drawn in January and those for series "B" in August.
23	Huddersfield -	100,000	Combined	7,000,000	Trade sewage	*1·00*	*0·60*	*10·40*	*40·0*‡	—	24 hours	*1·91*	*0·49*	*6·16*	*13·1*	1,000 to 10,000.	Every 6 months	Lagooned	Experimental process. Fixed quantity treated daily.
24	Knowle - -	1,600	Partially separate.	41,000	Domestic	4·02	0·71	8·07	19·4§	At least 100,000.	15·2 hours	3·46	0·52	5·62	8·4§	—	—	Spread over adjacent land.	
25	Leeds - -	450,142	Combined	16,000,000	Trade sewage	*2·57* *2·63*	*0·71* *0·90*	*11·20* *11·77*	*63·0* C. *59·8* P.	About 100,000.	24 hours	*1·52* *1·95*	*0·49* *0·44*	*7·80* *6·07*	*25·7* C. *17·8* P.	10,000 to 100,000.	End of 2 years	Lagooned	Experimental process (large scale); compare series "C" with contact effluent and series "P" with percolating filter effluent.
26	Manchester -	575,000	Ditto	25,300,000	Ditto	*2·27*	*0·51*	*10·50*	*35·0*	10,000 to 100,000.	15 hours	*2·74*	*0·37*	*8·69*	*10·8* app.	10,000 to 100,000.	—	Sent to sea	
27	Prestolee - -	500	Separate	18,000	Very weak (slop water) domestic	0·42	0·15	3·57	5·4*	About 1,000	22·0 hours	0·52	0·17	2·84	3·2*	1,000 to 10,000.	After 7½ years	Lagooned	
28	Rochdale - -	52,000	Combined	1,310,000	Domestic, with wool washings.	4·16	1·29	26·55	36·7	At least 100,000.	30·0 hours	3·74	0·67	10·92	5·3	10,000 to 100,000.	Every 6 months	Pressed and sold to farmers.	Experimental process. Fixed quantity treated daily.
29	Sheffield -	400,000	Ditto	14,500,000	Trade sewage	*2·61*	*0·76*	*7·08*	*50·2*	—	24 hours	*1·96*	*0·37*	*4·19*	—	—	At long intervals	Lagooned	Experimental process.
30	Slaithwiate -	3,000	Partially separate.	140,000	Weak domestic.	1·66	0·40	4·60	10·7§	Usually 100,000.	13·6 hours	1·79	0·37	3·88	7·1§	10,000 to 100,000.	No sludge removed for over 10 years.	—	
31	York - - -	80,000	Combined and partially separate.	4,250,000	Domestic, with trades waste.	2·58	0·82	13·83	21·2	At least 100,000.	26 hours	2·86	0·49	6·51	5·3	10,000 to 100,000.	After 21 months	Lagooned	Experimental process. Fixed quantity treated daily.

NOTE.—The figures of analysis given in ordinary type are, as a rule, averages of three sets of twenty-four hourly samples, drawn, in dry weather, according to rate of flow. The figures of analysis given in italics are, as a rule, averages of a large number of chance samples, drawn in all weathers. All figures for "Oxygen absorbed in four hours" given in italics having been obtained with "weak" permanganate must be multiplied by 1·6 to compare approximately with the figures for "oxygen absorbed in four hours" given in ordinary type, the latter having been obtained with "strong" permanganate. * Average analysis of Saltley sewage only. † Not quite dry weather samples. ‡ This figure represents the average quantity of suspended matter in the Huddersfield sewage, in dry weather. § Average of two samples only.

TABLE IV.—CHEMICAL PRECIPITATION, FOLLOWED BY SETTLEMENT,

No.	Place.	System of Sewerage.	Population draining to Works.	Dry weather flow of Sewage (gallons).	Nature of Sewage.	Analysis of Sewage (Parts per 100,000). Ammoniacal Nitrogen.	Albuminoid Nitrogen.	Oxygen absorbed in 4 hours.	Suspended Solids.	B. Coli per c.c.	Precipitant used and quantity added in grains per gallon.	Rate of flow in tanks (expressed in time taken to fill tanks in dry weather).	Analysis of precipitation liquor (parts per 100,000). Ammoniacal Nitrogen.	Albuminoid Nitrogen.	Oxygen absorbed in 4 hours.	Suspended Solids.	B. Coli. per c.c.	Tanks cleaned.	Method of Disposing of Sludge.	Remarks.
32	Calverley -	Combined	2,300	12,000	Strong domestic (mainly slop water).	11·82	1·80	29·55	31·90	At least 100,000	Alumino-ferric 17·5 grains based on dry weather flow.	47 hours	9·64	1·11	11·94	11·80	At least 100,000	No. 1 every month. No. 2 every two months.	Lagooned. Taken by farmer when dry.	
33	Chorley -	Ditto	27,000	900,000	Domestic	4·20	1·01	12·38	31·40	At least 100,000	Alumino-ferric 9·0 grains on average flow.	Quiescent for 1–2 hours.	3·82	0·55	4·77	3·11	10,000 to 100,000	Every two fillings.	Pressed and sold to farmers.	
34	Guildford -	Partially separate.	16,000	400,000	Domestic with brewery waste.	7·38	2·10	21·33	37·1	At least 100,000	Alumino-ferric 8·0 grains on average flow.	10½ hours	7·34	1·33	20·04	14·6	At least 100,000	Every two days.	Pumped into trenches and covered over.	
6	Hendon, High Level.	Ditto	23,500	650,000	Domestic	† 3·0 app.	† 1·0 app.	11·01	*23·9	About 100,000	Alumino-ferric 5 grains on average flow.	12 hours	3·62	0·42	5·50	*6·1	About 100,000	Twice a week to once a month according to position of tank in the series.	Pumped into trenches on land.	
35	Hendon, Low Level.	Ditto	23,500	300,000	Domestic with laundry waste.	† 4·0 app.	† 1·3 app.	17·55	*33·4	About 100,000	Alumino-ferric 6·0 grains on average flow.	12 hours	4·88	0·76	7·25	*4·1	About 100,000			
36	Heywood -	Combined	23,500	630,000	Domestic with trade waste.	*3·37*	*0·83*	*7·89*	‡*29·0*	At least 100,000	Alumino-ferric 8·0 grains on average flow,	24 hours	*1·99*	*0·42*	*3·38*	*4·0*	About 100,000	—	Pressed and taken by farmers.	
37	Horfield -	Partially separate.	2,500	38,000	Domestic with laundry waste.	3·80	1·02	9·39	35·6	At least 100,000	Alumino-ferric 5·0 grains on average flow.	17 hours	3·31	0·32	3·12	2·5	10,000 to 100,000	Every two days.	Pressed and taken by farmers.	
38	Huddersfield	Combined	100,000	7,000,000	Trade sewage.	*1·00*	*0·60*	*10·40*	*40·0*		Lime and copperas.	6 hours	*1·21*	*0·33*	*5·74*	*7·0*	—	—	Lagooned	
39	Kingston -	—	53,454	2,750,000	Domestic with trade waste.	3·85	0·86	10·66	31·0	At least 100,000	Alumino-ferric blood, charcoal, and clay, 50 grains on average flow.	6½ hours	3·64	0·44	5·17	1·5	10,000 to 100,000	First tanks every six days, second and third once a fortnight.	Pressed, dried and sold as manure.	
40	Leeds -	Combined	450,000	15,500,000	Trade sewage	*1·84* *2·07*	*0·60* *0·76*	*10·8* *12·1*	*60·1* G. *62·4* P.	About 100,000	Lime 3 grains on average flow.	4 hours 12 hours	*1·68* *2·00*	*0·31* *0·32*	*4·61* *4·16*	*11·1* G. *6·3* P.	—	—	Lagooned	Experimental process Analysis G. refers to the general precipitation liquor and Analysis P. is for comparison with percolating filter effluent
41	Maidstone -	Partially separate.	34,000	1,500,000	Domestic with brewery and tannery waste.	3·51	1·52	21·03	*34·8	At least 100,000	Lime 5 grains on average flow.	1½ hours	3·53	0·99	10·71	*14·0	—	Every two weeks.	Pressed and taken by farmers.	
42	Normanton	Combined	12,600	175,000	Domestic (mainly slop water).	6·95	1·50	29·25	*55·0	At least 100,000	Alumino-ferric 6–7 grains on dry weather flow.	14½ hours	4·90	0·68	10·32	*14·0	10,000 to 100,000	Every week	Lagooned and taken by farmers when dry.	
43	Rochdale -	Ditto	52,000	1,310,000	Domestic with wool scouring liquor.	4·16	1·29	26·55	*36·7	At least 100,000	Alumino-ferric 7·3 grains Vitriol 4·7 grains on average flow.	14½ hours	4·20	0·66	13·17	*7·8	1,000 to 10,000	Every three or four weeks.	Pressed and taken by farmers.	
44	Sheffield -	Ditto	400,000	14,500,000	Trade sewage.	*2·61*	*0·76*	*7·08*	*50·2*	—	Lime	Quiescent for 45 minutes.	*1·09*	*0·15*	*2·80*	*4·8*	—	—	Lagooned	
45	Withnell -	Partially separate.	1,650	15,000	Strong domestic (mainly slop water).	5·35	1·23	21·19 17·22	33·9 A. 19·6 B.	At least 100,000	Alumino-ferric 15 grains on dry weather flow.	Quiescent for several hours.	— 4·35	— 0·47	— 7·95	— 2·0 app. B.	100 to 1,000	Every one or two fillings.	Lagooned	Analysis A. is an average analysis of Withnell sewage. Analysis B. is an average analysis made on samples of sewage drawn for comparison with the precipitation liquor.
46	York -	—	80,000	—	Domestic with trade waste.	2·58	0·82	13·83	21·2	At least 100,000	Alumino-ferric 5·7 grains. Lime 4·3 grains on average flow.	7 hours	2·63	0·54	7·76	8·9	About 10,000	Every four days.	Pressed and buried thick under layer of soil.	

NOTE.—The figures of analysis given in ordinary type are, as a rule, averages of three sets of twenty-four hourly samples drawn, in dry weather, according to rate of flow. The figures of analysis given in italics are, as a rule, averages of a large number of chance samples drawn in all weathers. All figures for "oxygen absorbed in four hours" given in italics, having been obtained with "weak" permanganate, must be multiplied by 1·6 to compare approximately with the figures for "oxygen absorbed in four hours" given in ordinary type, the latter having been obtained with "strong" permanganate. * These were not quite dry weather samples. † These figures are inferred. ‡ Grit is not included in this figure.

TABLE V.—CONTACT BED FILTRATION.

No.	Place.	Number of contacts given.	Material.	Size of Material.	Depth of Material.	Distribution.	Average number of fillings per day. Primary beds only.	Rate of treatment per cube yard per day. Whole area included.	Analysis of final effluents. Parts per 100,000. Ammoniacal Nitrogen. Hourly.	Ammoniacal Nitrogen. Chance.	Albuminoid Nitrogen. Hourly.	Albuminoid Nitrogen. Chance.	Oxidised Nitrogen. Hourly.	Oxidised Nitrogen. Chance.	Oxygen absorbed in 4 hours. Hourly.	Oxygen absorbed in 4 hours. Chance.	Incubator test. (smell.) Hourly.	Incubator test. (smell.) Chance.	Suspended Solids. Hourly.	Suspended Solids. Chance.	Dissolved oxygen taken up in 24 hours. Hourly.	Dissolved oxygen taken up in 24 hours. Chance.	B. Coli per c.c.	Condition of Filters.	Remarks.
CRUDE SEWAGE.																									
1	Hampton	3	Clinker	Primary—coarse Secondary—medium. Tertiary—very fine	4 ft.	None on primary beds, half pipes and grips on secondary and tertiary beds.	About 3	Gallons. 43 Based on dry weather flow.	–	0·71	–	0·11	–	2·64	–	1·31	–	12+ in 12.	–	Trace	–	0·38	About 1,000 to 100,000.	Crude sewage clogged primary beds in one year, and partially settled sewage in 4 years.	
2c	Leeds	2	Coke	Primary—coarse Secondary—medium.	Primary, 5ft. Secondary, 6 ft.	None	Ditto	About 32	–	*0·44*	–	*0·09*	–	*0·37*	–	*0·75*	–	–	–	*2·5*	–	–	—	Primary bed lost capacity seriously in first 4 months.	Experimental process. Large scale. Fixed quantity treated daily.
3	Maidstone	2	Clinker	Primary—coarse Secondary—fine	Primary, 3 ft. 4 in. Secondary, 4 ft. 4 in.	Half pipes	0·86	23·7	–	0·92	–	0·22	–	1·23	–	2·52	–	7+ in 8.	–	1·31	–	–	10,000 to 100,000.	Primary bed in good order after 5 years.	Experimental process. Fixed quantity treated daily
4	Newton	1	Ditto	Medium to coarse	3 ft. 6 in.	Troughs	1·7	91	3·40	*0·59	–	*0·37	Trace	0·16	6·79	5·78	2– in 2.	6– in 6.	8·5	*6·9	–	More than 6·2	About 100,000.	Beds seriously clogged on surface after about 5 years.	
5	Withnell	2	Ditto	Primary—rather coarse. Secondary—medium.	Primary, 5 ft. Secondary, 3 ft. 6 in.	Ditto	0·71	18·2	0·89	†0·63	0·41	*0·12	0·0	2·48	3·86	1·71	3– in 3.	3+ in 3.	5·5	About 1·0	–	*0·66	At least 100,000.	Primary beds becoming seriously clogged after 5 years.	Experimental process. Fixed quantity treated daily.
SETTLED SEWAGE.																									
8	Halton	2	Primary—coke, clinker and stone. Secondary—coke.	Primary, Secondary } rather coarse	Primary 4 ft. 3 in. Secondary, 3 ft. 3 in.	Ditto	About 4	80	–	*1·54	–	*0·23	–	†0·88	–	2·52	–	2+ in 5.	–	About 3·0	–	–	About 10,000 to 100,000.	Primary beds clogged after 4 years.	
13	Oldham	1	Clinker	Medium to coarse	3 ft. to 1 ft. 6 in.	Troughs	—	About 100	–	*1·51*	–	*0·23*	–	*0·31*	–	*0·99*	–	–	–	*5·1*	–	–	—	—	—
11	Oswestry	2	House cinders	Primary, Secondary } medium to coarse	All beds, 4 ft. 6 in.	Ditto	4–5	51·4	–	0·56	–	0·18	–	1·16	–	1·76	–	8+ in 10.	–	About 2·0	–	*0·72	About 10,000.	Primary beds clogged up after about 3 or 4 years	
12	Sheffield	2	Clinker	Primary, Secondary } medium to fine.	3 ft.	Grips in material.	3	60	–	*0·34*	–	*0·06*	–	*1·64*	–	*0·60*	–	–	–	*1·8*	–	–	—	—	Experimental process.
SEPTIC TANK LIQUOR.																									
15	Andover	1	Ditto	Medium to fine	4 ft.	Half pipes	1·4	115 Based on dry weather flow.	4·82	4·10	*0·60	*0·52	0·0	*0·43	4·26	4·02	3– in 3.	1+ in 11.	9·8	9·6	–	*2·77	About 10,000 to 100,000.	Material had to be washed after about 4 years.	
17	Burnley	2	Ditto	Primary—coarse Secondary—fine	- -	Troughs	2	45	–	–	–	*0·06*	–	*1·06*	–	*0·78*	–	–	–	–	–	–	—	Material in No. 5 primary bed had to be washed after 3½ years.	
19	Exeter, (St. Leonards).	1	Clinker and coke	Fine to medium	5 ft.	Half pipes	3	105	1·00	0·55	–	0·11	1·49	*1·69	0·85	1·08	3+ in 3.	6+ in 6.	0·9	About 0·6	–	*0·62 ‡	About 100,000.	Material showing signs of clogging after 9 years' work.	
20	Exeter (Main works).	1	Clinker	Medium	4 ft. 6 in.	Ditto	2	55 Based on dry weather flow.	3·12	1·61	†0·47	0·31	*0·28	*1·63	3·67	4·42	3– in 3.	7+ in 14.	4·6	5·5	–	*1·69	About 100,000.	Beds had lost nearly half their water capacity after about 3 years.	
21	Guildford	2	Burnt ballast or clinker.	Primary—rather coarse. Secondary—rather fine.	2 ft. 6 in.	Grips in material.	2	22·7	–	‡1·08	–	†0·32	–	1·22	–	2·77	–	4+ in 7.	–	About 1·0	–	–	About 100,000.	Primary beds had lost nearly ⅓ of their capacity after about 4 years' work	Practically fixed quantity treated daily.

NOTE.—(*a*) All figures for "oxygen absorbed in four hours" given in italics, having been obtained with "weak" permanganate, must be multiplied by 1·6 to compare approximately with the figures for "oxygen absorbed in four hours" given in ordinary type, the latter having been obtained with strong permanganate. (*b*) The figures for albuminoid nitrogen in ordinary type may probably be rather too high in the case of some of the effluents.
* The figures are approximate. † These figures are averages of two samples only. ‡ These are averages of three samples only.

TABLE V.—CONTACT[ED] FILTRATION—*continued.*

No.	Place.	Number of contacts given.	Material.	Size of material.	Depth of Material.	Distribution	Average number of fillings per day. Primary beds only.	Rate of treatment per cube yard per day. Whole area included.	Analysis of final effluents. Parts per 100,000. Ammoniacal Nitrogen. Hourly.	Ammoniacal Nitrogen. Chance.	Albuminoid Nitrogen. Hourly.	Albuminoid Nitrogen. Chance.	Oxidised Nitrogen. Hourly.	Oxidised Nitrogen. Chance.	Oxygen absorbed in 4 hours. Hourly.	Oxygen absorbed in 4 hours. Chance.	Incubator test. (smell.) Hourly.	Incubator test. (smell.) Chance.	Suspended Solids. Hourly.	Suspended Solids. Chance.	Dissolved oxygen taken up in 24 hours. Hourly.	Dissolved oxygen taken up in 24 hours. Chance.	B. Coli. per c.c.	Condition of Filters.	Remarks.
SEPTIC TANK LIQUOR (*continued*).																									
22	Hartley Wintney.	1	Clinker	Fine	4 ft.	Half pipes	2·0	Gallons. 73 Based on dry weather flow.	1·16	3·20	0·27	0·38	1·22	1·02	3·14	3·26	3 + in 3.	2 + in 7.	3·3	7·2	–	*2·36	About 1,000 to 10,000.	Beds seriously clogged after about 5 years.	
23	Huddersfield	2	Ditto	Primary—coarse Secondary—medium	Primary, 3 ft. 9 in. Secondary, 2 ft. 11 in.	Grits in material.	2·5	71	–	*0·18*	–	*0·15*	–	*0·49*	–	*1·53*	–	–	–	*1·8*	–	–	—	Primary bed lost 74 per cent. of its capacity after 4½ years.	Experimental process.
25C	Leeds -	2	Primary—clinker Secondary—coke.	Primary—medium Secondary—medium.	Primary 5 ft. Secondary, 6 ft.	Ditto	1·5	45	–	*0·28*	–	*0·05*	–	*1·75*	–	*0·51*	–	–	–	*0·3*	–	–	About 1,000 to 10,000.	Primary bed lost 80 per cent. of its capacity after 4 years.	Experimental process.
26	Manchester	1	Clinker	Medium	3 ft. 4 in.	Ditto	2 to 3	77	–	*1·62*	–	*0·15*	–	*0·30*	–	*2·73*	–	–	–	*5·4*	–	§41 %	About 1,000 to 10,000.	—	
29	Sheffield -	2	Ditto	Primary—rather coarse. Secondary—rather fine.	3 ft.	Ditto	3	About 60	–	*0·48*	–	*0·07*	–	*1·21*	–	*0·72*	–	–	–	–	–	‖0·43	—	—	Experimental process.
30	Slaithwaite-	1	Ditto	Medium	5 ft.	Troughs	1·5	62	–	‡0·84	–	‡0·17	–	0·57	–	2·15	–	2 + in 7.	–	About 2·0	–	1·52	About 10,000.	Surface material badly clogged after 4 years.	Practically fixed quantity treated daily.
PRECIPITATION LIQUOR.																									
32	Calverley -	1	Ditto	Fine to coarse	3 ft.	Ditto	About 0·7	30 Based on dry weather flow.	–	2·67	–	*0·30	–	0·33	–	3·57	–	4 + in 13.	–	8·8	–	*1·14	About 1,000 to 10,000,	Beds still in good order after 10 years' work.	
6 & 35	Hendon -	1	Pan breeze, burnt ballast and broken brick.	Fine to medium	5 ft.	Half pipe	2·5	—	1·72	–	†0·16	–	1·22	–	2·07	–	3 + in 3.	–	Trace	–	–	–	About 1,000 to 10,000,	Beds still in good order after 6 years.	
36	Heywood -	1	Sand Ashes Coke	Very fine Medium Coarse.	4 ft. 3 in.	Troughs	3	174	–	*1·87*	–	*0·18*	–	*0·46*	–	*0·96*	–	–	–	–	–	–	—	Bed still good after 10 years. Top ½ inch of sand is taken off once a month and allowed to weather.	
39	Kingston -	1	Clinker or coke	Medium	3 ft.	Ditto	4	250	1·96	1·45	†0·19	0·12	1·22	1·53	0·84	0·96	3 + in 3.	7 + in 7.	About 1·0	About 1·0	–	*0·18	About 1,000 to 10,000.	Coke bed retains 20 per cent. of its empty tank capacity after nearly 8 years. Clinker bed retains 32 per cent. after nearly 4 years.	
40	Leeds -	1	Clinker	Medium	3 ft. 6 in.	None	3	—	–	*1·47*	–	*0·19*	–	*0·07*	–	*1·45*	–	–	–	*6·4*	–	–	—	Bed lost capacity rapidly owing to consolidation of material.	
38	Huddersfield	2	Ditto	Primary—medium Secondary—fine medium.	3 ft. 3 in.	—	2·5	100	–	*0·09*	–	*0·08*	–	*0·86*	–	*1·10*	–	–	–	*2·1*	–	–	—	No. 10 bed lost 68 per cent. of its capacity in 6 years.	

NOTE.—(*a*) All figures for "oxygen absorbed in four hours" given in italics, having been obtained with "weak" permanganate, must be multiplied by 1·6 to compare approximately with the figures for "oxygen absorbed in four hours" given in ordinary type, the latter having been obtained with strong permanganate. (*b*) The figures for albuminoid nitrogen in ordinary type may probably be rather too high in the case of some of the effluents.
* These figures are approximate. † These figures are averages of two samples only. ‡ These are averages of three samples only. § Percentage of dissolved oxygen taken up in forty-eight hours at 80°F. ‖ At 60°F.

TABLE VI.—PERCOLATING FILTERS

No.	Place.	Material used in Filters.	Size of Material.	Depth of Material.	Distribution.	How Liquid is delivered to Filter.	Rate of filtration per square yard per day.	Rate of filtration per cube yard per day.	Analysis of Final Effluent (Unsettled). Ammoniacal Nitrogen. Hourly.	Ammoniacal Nitrogen. Chance.	Albuminoid Nitrogen. Hourly.	Albuminoid Nitrogen. Chance.	Oxidised Nitrogen. Hourly.	Oxidised Nitrogen. Chance.	Oxygen absorbed in 4 hours. Hourly.	Oxygen absorbed in 4 hours. Chance.	Incubator test (by smell). Hourly.	Incubator test (by smell). Chance.	Dissolved Oxygen taken up in 24 hours. Hourly.	Dissolved Oxygen taken up in 24 hours. Chance.	Suspended Solids. Hourly.	Suspended Solids. Chance.	B. Coli. per c.c.	Condition of Filters.	Remarks.
CRUDE SEWAGE.							Gallons.	Gallons.																	
6	Hendon	Clinker	Medium	8 or 10 feet	Tipping troughs	Continuously	125	About 40	1·06	0·57	0·28	0·13	2·37	3·51	2·65	1·87	3 + in 3.	9 + in 9.	–	*0·62	6·3	5·2	—	No. 2 Filter (8 feet) good after 8 years.	Experimental Duca Filters. Fixe quantity treated daily.
2D	Leeds	Ditto	Ditto	10 feet	Ditto	Ditto	83	25	–	*0·19*	–	*0·05*	–	*1·21*	–	*0·34*	–	–	–	–	–	–	About 1,000.	Clogged after 1 month's work.	Ducat Experimental Filter. Fixed quantity treated daily.
2L	Leeds	Ditto	Very coarse	11½ feet	Sprinkler	Intermittently	200	52	–	*0·72*	–	*0·27*	–	*0·35*	–	*3·09*	–	–	–	–	–	*21·0*	About 10,000.	Choked with growth after 21 months.	Experimental "Leeds" Filter. Fixed quantity treated daily.
SETTLED SEWAGE.																									
7	Clifton	Cinders or sand and cinders	Fine to coarse Very fine to coarse	4 feet	By fine material	Ditto	20·8 Based on dry weather flow.	15·6	0·80	0·95	0·10	0·20	0·82	1·16	1·10	2·06	3 + in 3.	5 + in 7.	–	0·93	3·3	5·6	100 to 10,000.	Sand filter good after 14 years.	
10	Leeds	Coke	Coarse	9 ft. 6 ins.	Sprinkler	Continuously	200	63	–	*0·31*	–	*0·13*	–	*1·27*	–	*1·71*	–	–	–	–	–	*12·0*	—	Unchanged after 1 year.	Experimental process. Fixed quantity treated daily.
9	Little Drayton.	Granite	Medium	7 ft. 6 ins.	Tipping troughs	Ditto	48·5	19·5	0·78	0·57	0·22	0·18	3·60	4·51	2·92	2·45	3 + in 3.	4 + in 4.	0·74	*0·92	10·1	8·0	1,000 to 10,000.	Necessary to wash upper part of material after 3 or 4 years.	
SEPTIC TANK LIQUOR.																									
14	Accrington	Coke or clinker	Coarse	9 ft. 3 ins. to 7 feet.	Sprinklers	Ditto	425	140	1·07	1·33	0·27	0·25	2·24	1·60	5·08	3·02	4 + in 4.	11 + in 11.	–	*0·96	20·0	8·9	Ditto	Good after 4 to 8 years.	
16	Birmingham	Granite, quartzite, slag, etc.	Coarse	6 feet	Nozzles, etc.	Ditto	165	82·5	*2·86*	–	*0·29*	–	*2·11*	–	*2·58*	–	*all* +	–	–	–	*7·3*	–	—	—	
18	Caterham	Coke	Medium to coarse	5 feet	Perforated pipes	Intermittently	51	30·7	6·77	8·88	0·42	0·41	8·90	7·95	5·22	5·11	4 + in 4.	7 + in 7.	–	0·80	*3·7	3·8	About 1,000.	Good after 10 years.	Fixed quantity treated daily.
23	Huddersfield	Clinker	Coarse	7 feet	Sprinkler	Continuously	258	110	–	†*0·23*	–	†*0·09*	–	†*1·03*	–	†*1·29*	–	–	–	–	–	–	Ditto	Good after 1 year	Experimental process. Fixed quantity treated daily.
24	Knowle	Ditto	Ditto	6 feet	Stoddart trays	Ditto	1,000	2,000	3·19	4·07	0·34	0·48	*0·90	0·60	2·70	4·11	3 – in 3.	5 + in 12.	–	*2·28	3·77	3·9	About 100,000.	Good after about 4 years.	
25D	Leeds	Coke	Ditto	9 ft. 6 ins.	Sprinkler	Ditto	200	63	–	*0·51*	–	*0·14*	–	*1·08*	–	*1·60*	–	–	–	–	–	*11·4*	About 1,000.	Good after 4 years' work. Bed twice flushed out with town's water.	Experimental process, Fixed quantity treated daily.

NOTE.—(*a*) All figures for "oxygen absorbed in four hours" given in italics, having been obtained with "weak" permanganate, the latter having been obtained with "strong" permanganate. (*b*) The figures for albuminoid nitrogen, in ordinary type, may probably be rather too high in the case of some of the effluents.
* These figures are approximate. † This analysis was made after suspended solids had been settled out.

TABLE VI.—PERCOLATING FILTERS—*continued.*

No.	Place.	Material used in Filters.	Size of Material.	Depth of Material.	Distribution.	How Liquid is delivered to Filter.	Rate of filtration per square yard per day.	Rate of filtration per cube yard per day.	Analysis of Final Effluent (Unsettled). Ammoniacal Nitrogen. Hourly.	Ammoniacal Nitrogen. Chance.	Albuminoid Nitrogen. Hourly.	Albuminoid Nitrogen. Chance.	Oxidised Nitrogen. Hourly.	Oxidised Nitrogen. Chance.	Oxygen absorbed in 4 hours. Hourly.	Oxygen absorbed in 4 hours. Chance.	Incubator test (by smell). Hourly.	Incubator test (by smell). Chance.	Dissolved Oxygen taken up in 24 hours. Hourly.	Dissolved Oxygen taken up in 24 hours. Chance.	Suspended Solids. Hourly.	Suspended Solids. Chance.	B. Coli. per c.c.	Condition of Filters.	Remarks.
							Gallons.	Gallons.																	
SEPTIC TANK LIQUOR (*continued*).																									
27	Prestolee -	Cinders and gravel	Fine to coarse	5 feet	By fine material	Intermittently	92·7	55·6	0·13	0·05	0·03	0·02	0·33	0·90	0·31	0·41	3 + in 3.	6 + in 6.	–	*0·04	None	None	100 to 1,000.	Good after 8 years.	
28	Rochdale -	Coke	Coarse	9 feet	Sprinkler	Continuously	424	141	–	0·08	–	0·10	–	*2·76	–	2·56	–	5 + in	–	*0·32	–	7·4	About 100 to 1,000.	Good after 7 years.	Fixed quantity treated daily
31	York - -	Clinker, coke, slag or broken brick.	Ditto.	6 ft. 6 ins. by 7 ft. 8 ins.	Ditto.	Ditto.	360	About 150	0·10	0·25	0·07	0·15	2·25	2·11	1·17	1·82	3 + in 3.	7 + in 7.		0·32	1·80	5·0	Ditto.	Good after 4 and 6 years.	Ditto.
PRECIPITATION LIQUOR.																									
33	Chorley -	Sand, polarite, and gravel.	Very fine to coarse	3 feet	By fine material	Intermittently	525	525	1·07	0·56	0·09	0·11	2·35	3·00	1·03	0·98	3 + in 3.	12 + in 12.	–	0·18	Trace	Trace	About 1,000 to 10,000.	Good after 12 years.	
37	Horfield -	Clinker	Coarse	7 ft. 5 ins.	Stoddart trays	Continuously	478	190	1·69	2·26	0·15	0·23	2·19	*1·19	1·60	2·47	3 + in 3.	12 + in 12.	–	*0·54	3·65	7·0	About 10,000.	Good after 5 years.	
40P	Leeds -	Coke	Ditto.	6 feet	Sprinkler	Intermittently	100	50	–	*0.34*	–	*0·07*	–	*1·66*	–	*0·67*	–	–	–	–	–	*2·0*	—	Good after 1 year.	Experimental process. Fixed quantity treated daily. Filter worked subsequently at double this rate with good results.
42	Normanton-	Sand, polarite, and gravel.	Very fine to coarse	3 ft. 3 ins.	By fine material	Ditto.	—	—	2·58	1·42	0·16	0·10	1·33	3·00	1·86	1·27	3 + in 3.	10 + in 11.	–	*0·69	Trace	Trace	About 1,000 to 10,000.	Good after 10 years.	Fixed quantity treated daily.
45	Withnell -	Ditto.	Ditto.	3 feet	Ditto.	Ditto.	68·6 Based on dry weather flow.	63·5	2·71	1·68	0·16	0·08	1·62	0·84	1·65	1·29	3 + in 3.	3 + in 4.	0·49	0·28	Trace	Trace	About 100 to 1,000.	Good after 6 and 12 years.	
6 and 35	Hendon -	Coke breeze, burnt ballast, and broken brick.	Fine to coarse	5 feet	Ditto.	Ditto.	—	—	1·28	–	0·09	–	1·56	–	1·48	–	3 + in 3.	–	–	–	Trace	–	About 1,000.	Good after 7 years.	

NOTE.—All figures for "oxygen absorbed in four hours" given in italics, having been obtained with "weak" permanganate must be multiplied by 1·6 to compare approximately with the figures for "oxygen absorbed in four hours," given in ordinary type the latter having been obtained with "strong" permanganate. (*b*) The figures for albuminoid nitrogen in ordinary type, may probably be rather too high in the case of some of the effluents. * These figures are approximate.

TABLE VII.—PERCOLATING FILTERS.

SUPPLEMENTARY TABLE SHOWING ANALYSIS OF *Settled* EFFLUENTS.

No.	Place.	How Effluent from Continuous Filter is settled.	Analysis of Settled Effluent. Parts per 100,000. Ammoniacal Nitrogen. Hourly.	Ammoniacal Nitrogen. Chance.	Albuminoid Nitrogen. Hourly.	Albuminoid Nitrogen. Chance.	Oxidized Nitrogen. Hourly.	Oxidized Nitrogen. Chance.	Oxygen absorbed in 4 hours. Hourly.	Oxygen absorbed in 4 hours. Chance.	Incubator Test (by smell). Hourly.	Incubator Test (by smell). Chance.	Suspended Solids. Hourly.	Suspended Solids. Chance.	Dissolved Oxygen taken up in 24 hours. Hourly.	Dissolved Oxygen taken up in 24 hours. Chance.	Remarks.
CRUDE SEWAGE.																	
2	Leeds - -	Tank.	–	*0·61*	–	*0·16*	–	*0·44*	–	*1·47*	–	–	–	*6·1*	–	–	Experimental "Leeds" Filter. Fixed quantity treated daily.
		Fine filtered.	–	*0·52*	–	*0·10*	–	*0·59*	–	*0·93*	–	–	–	*3·5*	–	–	
SETTLED SEWAGE.																	
10	Leeds - -	Filtered through fine material.	–	*0·27*	–	*0·07*	–	*1·40*	–	*0·90*	–	–	–	*6·0*	–	–	Experimental process. Fixed quantity treated daily.
SEPTIC TANK LIQUOR.																	
14	Accrington -	Tanks. One hour continuous flow settlement.	0·58	0·91	0·06	0·16	2·20	1·69	2·69	2·36	3 + in 3	13 + in 13	3·60	5·49	–	0·48*	
16	Birmingham -	Dortmund Tanks.	*3·12*	–	*0·17*	–	*1·70*	–	*2·01*	–	*all* +	–	*1·8*	–	–	–	Large scale.
18	Caterham -	Passed through tank filled with coarse flints.	6·84	9·21	0·33	0·37	8·52	6·67	3·77	4·03	4 + in 4	11 + in 11	0·8	1 to 2	–	0·60	Only one-third of sewage filtered. Fixed quantity treated daily
25P	Leeds - -	Settled, or filtered through fine material.	–	*0·51*	–	*0·08*	–	*1·06*	–	*0·70*	–	–	–	*3·0*	–	–	Experimental process. Fixed quantity treated daily.
28	Rochdale -	Tanks. Two hours continuous flow settlement.	6·47	0·08*	0·13	0·08†	2·18	2·46*	1·68	1·46	3 + in 3	8 + in 8	2·2	4·50	–	0·29*	Experimental process. Fixed quantity treated daily.

NOTE. (*a*) The figures for oxygen absorbed in four hours given in italics, having been obtained with "weak permanganate," must be multiplied by 1·6 to compare approximately with the figures for "oxygen absorbed in four hours," given in ordinary type, the latter having been obtained with "strong" permanganate.
(*b*) The figures for albuminoid nitrogen in ordinary type may probably be rather too high in some of the above effluents.
* These figures are approximate. † This is an average of only two samples.

PART III.—PURIFICATION OF SEWAGE BY TREATMENT ON LAND.

INTRODUCTORY REMARKS.

192. There can be no doubt that, where the soil is suitable and the area of land sufficient, the organic matters in sewage can be thoroughly oxidised by land treatment.

This fact is well established, not only by investigations made by earlier Commissions, but also by wide general experience.

The investigations of earlier Commissions did not, however, extend to the bacteriological side of the question, and for this reason, and in order to compare the treatment of sewage on land with its treatment by other methods, we considered it necessary to examine the working of some sewage farms.

Prior to commencing our investigations, a large number of sewage farms were visited, and we ultimately selected, for systematic observation, the following farms :—

Aldershot Camp - - - -	Sand.
Croydon (Beddington) - - -	Gravelly loam.
Nottingham - - - -	Light loam.
Cambridge - - - - -	" "
South Norwood - - - -	Heavy loam and clay.
Leicester - - - - -	" " "
Altrincham - - - - -	Peaty soil and sand.
Rugby (high level farm) - -	Heavy loam.

Some few samples of effluent were also taken from, and some observations made at, Luton (chalk), Worsley (peat and gravel), Hemsworth (clayey soil), Derby County Asylum (stiff soil overlying red clay), Lindfield (clayey soil), Sandhurst (sandy soil), and Woking (Bagshot sand).

Our investigations extended over a period of more than two years, and detailed particulars in regard to them are contained in the Reports made to us by our officers, which were published as supplementary volumes to our Fourth Report.

COMPARISON OF EFFLUENTS FROM LAND AND FROM ARTIFICIAL FILTERS.

193. Judged by chemical analysis, both classes of effluent possess similar qualities.

As regards the eight farms which we have had under observation, the average purification, calculated on the atmospheric oxygen used up, and giving credit for the oxygen contained in the effluent in the form of nitrate, was about 98 per cent. It would have been rather higher than this if the suspended solids had been eliminated from those effluents which contained them.

As regards seven contact bed plants, which we have examined, the average purification on the same basis, but eliminating the suspended solids, was 93·4 per cent.

As regards six installations of percolating filters, our analyses show that the average purification, after eliminating the suspended solids, was 99·4 per cent.

The following tables, A and B, give the average figures of the chemical analyses of the sewage and effluents at the eight farms; Table C gives certain percentages for each farm.

Table A—Table of Average Figures showing the Chemical Composition of the Sewages at the selected Sewage Farms.

Name of Farm. Number of Samples of Sewage Examined.	Altrincham. 4 Chance samples of sewage and 5 of lagoon liquor.	Aldershot Camp. 9 Chance samples and 3 sets of hourly samples.	Croydon (Beddington). 5 to 7 Chance samples and 7 sets of hourly samples.	Cambridge. 5 Chance samples and 3 sets of hourly samples.	Leicester. 5 Chance samples and 3 sets of hourly samples.	Nottingham. 4 Chance samples and 3 sets of hourly samples.	Rugby. 8 Chance samples and 3 sets of hourly samples.	South Norwood. 4 to 7 Chance samples and 7 sets of hourly samples.
Parts per 100,000 *by weight.*	Average.	Average.	Average.	Average.	Average.	Average.	Average.	Average.
Total Nitrogen :—Chance samples.	2·06 to 5·01 = **3·56**	12·45 to 24·89 = **17·6**	6·82 to 13·42 = **9·50**	1·50 to 11·52 = **3·94**	2·90 to 8·61 = **5·57**	4·68 to 7·86 = **6·39**	2·80 to 14·94 = **9·95**	3·52 to 10·84 = **7·07**
Hourly samples.	—	12·31 to 14·24 = **13·3**	6·42 to 7·59 = **7·18**	5·60 to 5·80 = **5·71**	7·32 to 9·16 = **8·12**	7·53 to 7·82 = **7·69**	9·39 to 9·99 = **9·65**	4·46 to 5·63 = **5·20**
Ammoniacal nitrogen : — Chance samples.	0·69 to 3·69 = **2·29**	8·26 to 16·94 = **12·30**	4·15 to 9·71 = **7·34**	0·89 to 7·31 = **2·41**	2·90 to 8·61 = **5·57**	3·21 to 5·32 = **3·92**	1·95 to 11·21 = **7·37**	5·35 to 7·60 = **6·50**
Hourly samples.	—	7·60 to 8·21 = **7·87**	4·18 to 5·11 = **4·50**	3·77 to 3·85 = **3·82**	7·32 to 9·16 = **8·12**	3·08 to 4·53 = **3·98**	5·74 to 6·46 = **6·11**	3·15 to 4·05 = **3·54**
Total organic nitrogen :—Chance samples.	0·69 to 3·69 = **2·29**	3·39 to 9·10 = **5·35**	2·03 to 4·06 = **3·37**	0·39 to 4·09 = **1·25***	1·18 to 2·41 = **1·68***	1·47 to 4·24 = **2·42***	1·61 to 5·57 = **2·54**	2·04 to 3·24 = **2·55**
Hourly samples.	—	4·25 to 6·18 = **5·06**	1·31 to 2·88 = **2·07**	1·73 to 1·95 = **1·88**	2·10 to 2·53 = **2·34**	2·56 to 4·21 = **3·15**	2·87 to 3·55 = **3·29**	1·02 to 1·90 = **1·49**
Albuminoid nitrogen : — Chance samples.	0·20 to 1·14 = **0·62**	2·05 to 3·63 = **2·77**	0·99 to 2·36 = **1·72**	0·28 to 1·52 = **0·62**	0·66 to 1·70 = **1·11**	1·18 to 2·63 = **1·77**	0·40 to 2·84 = **1·49**	0·98 to 1·23 = **1·07**
Hourly samples.	—	1·54 to 1·69 = **1·62**	0·59 to 1·12 = **0·91**	0·89 to 0·96 = **0·91**	0·97 to 1·44 = **1·19**	1·17 to 1·99 = **1·45**	1·56 to 1·80 = **1·73**	0·55 to 1·04 = **0·67**
"Oxygen absorbed" from permanganate at 26·7° C. (80° F.) *in four hours* :—Chance samples.	2·29 to 6·98 = **5·22**	20·68 to 38·47 = **25·94**	7·91 to 18·73 = **13·70**	2·07 to 17·81 = **6·99**	7·77 to 16·41 = **12·45**	10·97 to 25·06 = **17·64**	3·55 to 33·31 = **15·0**	6·74 to 20·08 = **11·40**
Hourly samples.	—	19·54 to 22·40 = **20·79**	7·85 to 17·45 = **12·48**	9·49 to 10·68 = **10·08**	20·28 to 24·83 = **22·35**	21·03 to 26·29 = **23·12**	17·55 to 19·18 = **18·44**	5·43 to 9·77 = **7·71**
Chlorine :—Chance samples.	7·22 to 12·88 = **9·43**	8·90 (?) to 13·98 = **11·38**	5·70 to 10·50 = **8·15**	4·95 to 10·30 = **6·37**	3·51 to 11·94 = **8·10**	9·66 to 23·42 = **16·35**	4·86 to 18·30 = **11·68**	7·28 to 8·88 = **7·87**
Hourly samples.	—	11·36 to 19·78 = **14·98**	7·86 to 9·22 = **8·34**	7·90 to 8·74 = **8·45**	12·50 to 13·84 = **13·38**	11·25 to 15·36 = **13·68**	9·36 to 10·46 = **9·99**	7·08 to 8·00 = **7·45**
Solids in Suspension (gravimetrically) :—Hourly samples.	—	32·0 to 39·8 = **36·6**	21·2 to 53·0 = **34·5**	23·8 to 28·6 = **26·5**	33·6 to 34·8 = **34·1**	34·4 to 79·2 = **51·9†**	43·0 to 50·6 = **47·3**	9·6 to 38·2 = **21·9**
"Cellulose" in Solids in Suspension :—Hourly samples.	—	9·0 to 12·68 = **10·79**	—	3·84 to 5·08 = **4·48**	6·56 and 5·80 = **6·18**	5·32 to 15·08 = **8·88†**	5·88 to 7·92 = **7·22**	—
Parts per 100,000 *by Volume.*				—	—	—	—	—
Solids in Suspension, as determined by Centrifuge :—Chance samples.†	27 to 99 = **72** 2 sewages and 3 lagoon liqours.	—	—	146 to 176 = **160**	160 to 261 = **196**	—	258 to 345 = **304**	80 to 245 = **139**
Hourly samples.†	—	148 to 216 = **173**	173 to 356 = **218**					
*Ratio of Solids in Suspension to Centrifuge solids : —*Hourly samples.	—	1 : 3·9 to 1 : 5·4 = **1 : 4·7**	1 : 4·8 to 1 : 8·2 = **1 : 6·6**	1 : 5·5 to 1 : 6·5 = **1 : 6·0**	1 : 4·8 to 1 : 7·5 = **1 : 5·8**	—	1 : 6·0 to 1 : 7·1 = **1 : 6·4**	1 : 4·7 to 1 : 9·1 = **1 : ·6**
Ratio of "Celluloses" to Suspended Solids (grav.) :—Hourly samples.	—	1 : 8·1 to 1 : 11.2 = **1 : 9·7**	1 : 3·6 to 1 : 6·2 = **1 : 4·8**	1 : 5·6 to 1 : 6·2 = **1 : 5·9**	1 : 5·3 to 1 : 5·8 = **1 : 5·6**	1 : 5·3 to 1 : 6·7 = **1 : 6·2**	1 : 6·1 to 1 : 7·3 = **1 : 6·6**	—

*Note.—This is a comparison of a figure expressing weight with one expressing volume.

†These figures express the *volumes* of the muds.

* This figure is possibly too low.

* This figure is possibly too low.

*This figure is probably too low.
†These figures are probably higher than the normal.

TABLE B.—TABLE WITH SOME OF THE AVERAGE FIGURES SHOWING THE CHEMICAL COMPOSITION OF THE FINAL AND GENERAL EFFLUENTS AT THE SELECTED SEWAGE FARMS.

NAME OF FARM. Number of samples of effluents examined.*	ALTRINCHAM. 14 to 16	ALDERSHOT CAMP. 16 to 18	CROYDON (BEDDINGTON.) 15 to 16 (Of the final effluents two were over 2 fields only).	CAMBRIDGE. 17 to 18	LEICESTER. 8 to 13	NOTTINGHAM. 13	RUGBY. 16 to 19	SOUTH NORWOOD. 11 effluents (total nitrogen and "oxygen absorbed"); 6 effluents (ammoniacal and albuminoid nitrogen). These include three 2-field effluents.
Parts per 100,000 by weight.	Average.	Average.	Average.	Average.	Average.	Average.	Average.	Average.
Total nitrogen	1·36 to 4·99=2·22	3·69 to 8·99=6·0	1·02 to 3·49=2·20	1·48 to 3·19=2·09	1·84 to 3·64=2·53	1·41 to 3·45=2·27	1·39 to 2·96=2·31	0·55 to 2·83=2·30
Ammoniacal nitrogen	0·65 to 1·87=1·23	0·91 to 4·98=1·85	0·23 to 3·10=1·48	0·22 to 1·31=0·65	0·59 to 2·81=1·65	0·01 to 0·29=0·13	0·97 to 2·81=1·62	0·02 to 1·55=0·87
Albuminoid nitrogen	0·07 to 0·25=0·13	0·12 to 0·47=0·26	0·06 to 0·23=0·14	0·04 to 0·18=0·09	0·07 to 0·35=0·20	0·01 to 0·10=0·03	0·08 to 0·39=0·18	0·07 to 0·14=0·10
Total organic nitrogen	0·10 (?) to 0·45=0·26	—	0·09 to 0·55=0·26	0·04 (?) to 0·42=0·21	0·18 to 0·63=0·45		—	—
Nitric + nitrous nitrogen	0·0 to 3·64=0·76	0·0 (?) to 5·97=3·21	0·03 to 1·43=0·37	0·69 to 2·25=1·26	0·0 to 1·73=0·51	1·25 to 3·29=2·06 and 1·24 to 1·71 in four later samples..	0·0 to 1·59=0·52	0·14 to 0·74 (?)=0·39
"Oxygen absorbed" from permanganate at 26·7° C. (80° F.) *in four hours.*	0·32 to 2·65=1·75	1·02 to 5·68=2·72	0·90 to 2·09=1·41	0·16 to 1·31=0·81	1·70 to 4·47=2·50	0·05 to 0·37=0·19	0·72 to 2·16=1·41	0·97 to 1·73=1·44
Incubator test (as judged by smell).	81% passed (16 samples tested.)	89% passed (18 samples tested.)	73% passed (15 samples tested.)	94% passed (18 samples tested.)	92% passed (13 samples tested.)	100% passed (17 samples tested.)	75% passed (20 samples tested.)	75% passed (12 samples tested.)

* Some of the effluents were subjected to more tests than others.

TABLE C.—TABLE SHOWING APPROXIMATELY THE PERCENTAGE CHEMICAL PURIFICATION ON (a) ALBUMINOID NITROGEN AND (b) OXYGEN ABSORBED" FROM PERMANGANATE.

NAME OF FARM.	ALTRINCHAM.	ALDERSHOT CAMP.	CROYDON (BEDDINGTON).	CAMBRIDGE.	LEICESTER.	NOTTINGHAM.	RUGBY.	SOUTH NORWOOD.
(a) Calculated on Albuminoid nitrogen.	79%* On Chance samples of sewages and lagoon liquors together.	94% on Chance samples. 84% on Hourly samples.	92% on Chance samples. 89% on Hourly samples.	85% on Chance samples. 90% on Hourly samples.	82% on Chance samples. 85% on Hourly samples.	99% on Chance samples. 98% on Hourly samples.	88% on Chance samples. 89% on Hourly samples.	91% on Chance samples. 85% on Hourly samples.
(b) Calculated on "Oxygen absorbed" from permanganate at 26·7° C. (80° F.) *in four hours.*	67%*	90% on Chance samples. 87% on Hourly samples.	90% on Chance samples. 89% on Hourly samples.	88% on Chance samples. 92% on Hourly samples.	80% on Chance samples. 88% on Hourly samples.	99% on Chance samples. 99% on Hourly samples.	91% on Chance samples. 92% on Hourly samples.	87% on Chance samples. 81% on Hourly samples.

*This calculation is very approximate and of doubtful value.

These Tables show that the strength of the several sewages varied somewhat widely, that the average quality of the effluents from the several farms also varied, and further, that the effluents from the same farm were by no means of uniform quality.

Nottingham was the only farm from which none of the effluents which were examined putrefied upon incubation, and in this case the amount of sewage treated was only 10,750 gallons per acre per day, and very little storm water was treated.

Speaking generally, the effluents which we have examined from artificial filters, as at present constructed and used, are not equal in purity to effluents from the best land, when treating a comparatively small quantity per acre, as at Nottingham; but effluents from heavy land are often of very inferior quality. Moreover, in the case of some kinds of land, we think that the danger of some of the sewage escaping in an unpurified condition is greater than it is in the case of artificial filters, assuming equally careful management in the two cases.

Bacteriological Character of Effluents.

194. Our investigations have not shown that there is any essential bacteriological distinction between effluents from land and effluents from artificial filters, though effluents from land usually contain fewer micro-organisms than effluents from the artificial filters which are at present in use. The bacteria in the filter effluents can, however, be largely reduced, if this is necessary, by some additional process, such as sand filtration or sterilization,* but for the reasons which are given under the section of this Report dealing with standards, we do not consider that the further process would usually be required.

There is, no doubt, a greater retardation in the passage of an excremental organism through soil than through artificial filters, at the rates of working generally followed in the two cases: this is probably a factor of importance in relation to the life and virulence of certain pathogenic microbes.

The following table gives the average figures for the bacteriological analysis of the final effluents from the eight sewage farms, the figures in brackets shewing the percentage reduction in each case upon the original sewage treated.

	Altrincham.	Aldershot Camp.	Croydon (Beddington).	Cambridge.	Leicester.	Nottingham ‡.	Rugby.	South Norwood.
Total number of bacteria (Gelatine at 20°C.)	263,400 (99%)	183,266 (99%)	1,413,200 (95%)	711,476 (94%)	532,777 (95%)	Frequently less than 1,000.	637,133 (97%)	778,322 (98%)
Total number of bacteria (Agar at 37° C.)	7,275 (99%)	37,308 (99%)	112,000 (97%)	78,327 (94%)	70,500 (95%)	ditto	81,526 (97%)	35,157 (99%)
B. Coli. (†)	At least 100, but less than 1,000 per c.c.	At least 1,000, but less than 10,000 per c.c.	At least 1,000, but less than 10,000 per c.c.	At least 1,000, but less than 10,000 per c.c.	At least 1,000, but less than 10,000 per c.c.	Results variable: but usually very satisfactory in a relative sense.	At least 1,000, but less than 10,000 per c.c.	At least 100, but less than 1,000 per c.c.
B. Enteritidis Sporogenes test.	At least 1, but less than 10 per c.c.	At least 10, but less than 100 per c.c.	At least 10, but less than 100 per c.c.	At least 10, but less than 100 per c.c.	At least 10, but less than 100 per c.c.		At least 10, but less than 100 per c.c.	At least 10, but less than 100 per c.c.
Neutral red broth test (†).	+ ·01. c.c. − ·001 c.c.	+ ·01 c.c. − ·001 c.c.	+ ·001 c.c. − ·0001 c.c.		+ ·001 c.c. − ·001 c.c.		+ ·01 c.c. − ·0001 c.c.	

* *See* Dr. Houston's Report on Sterilization, Appendix IV.

(†) These averages are only approximate.

(‡) The effluents from the Nottingham farm stand in a class by themselves. Some of them were so pure bacteriologically as to resemble drinking water, but still the figures were variable. (For details, cf. Bacteriological Report to the Commission by Dr. A. C. Houston, Fourth Report, Vol. IV., Part III.)

From a bacteriological point of view, the treatment of sewage on land, may, under favourable conditions, reduce the bacteria to quite a remarkable extent. This is shown in the foregoing Table, the reduction both in the total number of bacteria and in the bacteria growing at 37° C. (blood heat) varying from 94 per cent. to 99 per cent. But, notwithstanding this large percentage reduction, it will be seen from Dr. Houston's detailed Report* that the number of microbes of undesirable sort remaining in the effluent may often be very great.

VOLUME OF SEWAGE WHICH CAN BE TREATED ON LAND.

195. The witnesses whom we examined on the question of the land treatment of sewage were not unanimous as to the basis on which the extent of land required should be calculated. Mr. F. Scudder and Mr. Santo Crimp considered that the basis should be the volume of sewage to be dealt with, but Mr. Baldwin Latham expressed the view that the area of land must be determined by the population draining to the farm, as indicating the strength of the sewage. The quality of the land itself must, of course, always be taken into account. Another factor to which importance was attached was the nature and extent of the preliminary treatment, if any, that the sewage receives before it is put on the land.

Scudder, 57(Santo Crimp 1573. 4662-4. 4515-16.

Generally speaking, the evidence points to a maximum rate of 30,000 gallons per acre, or 1,000 persons per acre, with the best land, after preliminary treatment, although some witnesses put the rate as high as 60,000 gallons per acre, or 2,000 persons per acre, under similar conditions. With unsuitable land, such as clay, not more than 3,000 gallons per acre can be efficiently treated, even after settlement of the sewage.

Santo Crimp, 1571-2. Strachan, 7629-30. Roscoe, 3741 & 374 Balfour, 6859-63. Tatton, 657 6578.

Mr. R. A. Tatton handed in the following Table showing the approximate areas required with different soils:—

—	Direct to Land.		After Precipitation or Mechanical Settlement.		After Filtration on Bacteria Beds.	
	Ratio of Population per Acre.	Acres per 1,000 Persons.	Ratio of Population per Acre.	Acres per 1,000 Persons.	Ratio of Population per Acre.	Acres per 1,000 Persons.
Broad Irrigation:						
Gravel	100	10	500	2	1,000	1
Light Loam	100	10	500	2	750	$1\frac{1}{5}$
Heavy Loam	75	$13\frac{1}{3}$	200	5	400	$2\frac{1}{2}$
Chalk	—	—	—	—	—	—
Peat	Unsuitable.	Unsuitable.	Unsuitable.	Unsuitable.	Unsuitable.	Unsuitable.
Clay	50	20	100	10	300	$3\frac{1}{3}$
Intermittent Filtration:						
Gravel	150	$6\frac{2}{3}$	500	2	1,000	1
Light Loam	150	$6\frac{2}{3}$	500	2	1,000	1
Heavy Loam	75	$13\frac{1}{3}$	300	$3\frac{1}{3}$	500	2
Chalk	—	—	—	—	—	—
Peat	75	$13\frac{1}{3}$	200	5	400	$2\frac{1}{2}$
Clay	Unsuitable.	Unsuitable.	Unsuitable.	Unsuitable.	Unsuitable.	Unsuitable.

196. With regard to the eight sewage farms which we had under our own observation, we give in the appended Table a statement of the nature and extent of the land, the volume dealt with, and a brief summary of our conclusions.

* *See* Vol. IV., part III., presented with our Fourth Report.

Name of Farm.	Nature of Sewage.	Nature of Soil and Subsoil.	Method of Treatment.	Area of Land under Treatment.	Volume treated per acre of land under treatment per 24 hours.	Population per acre of land under treatment.	Observations.
				Acres.	Gallons.		
Aldershot Camp	Domestic	Sand.	Screening, settling tanks and land filtration.	120½	8,300	166	The volume treated per acre was rather too large to yield effluents of the highest class, though the effluents showed a high percentage of purification. The sewage is exceptionally strong at Aldershot.
Altrincham	Domestic	Peaty soil, lying upon sand and gravel.	Settling tank and land filtration.	35	23,000	514	With a somewhat smaller volume of sewage per acre, probably the results would be distinctly good.
Cambridge	Mainly domestic	Sandy loam overlying gravel and sand.	Screening and settling tank and land filtration.	74	30,400	675	The effluents were usually good, but 30,400 gallons per acre was rather too large a volume to yield effluents of the highest class.
Croydon (Beddington) ...	Domestic	Gravelly loam over gravel and sand.	Screening and partly surface irrigation partly filtration.	420	9,500	238	With the method of treatment adopted 9,500 gallons per acre was too large a volume to yield an effluent of the highest class. If the 420 acres of land were laid out solely for filtration, no doubt a larger quantity of sewage could be treated per acre.
Leicester	¾ domestic; ¼ trade refuse	Stiff clayey soil overlying dense clay.	Screening, settling tanks, and surface irrigation and filtration combined.	1,350	5,370	146	The land was treating rather too large a volume per acre to yield effluents of the highest class.
South Norwood	Domestic	Clay soil resting on London clay.	Screening, settling tanks and surface irrigation.	152	4,000	138	The results indicated that rather too large a volume of sewage was put on the land to yield effluents of the highest class.
Nottingham	4/7 domestic, 3/7 trade refuse	Light sandy loam and gravel overlying gravel and sand.	Screening and land filtration.	651	10,750	397	The effluents were uniformly of exceptionally high quality, as judged by chemical analysis.
Rugby	Mainly domestic	Heavy loam overlying stiff clay.	Screening, chemical precipitation, settling tanks, and surface irrigation and filtration combined.	35	8,500	171	The volume treated on the land per acre was too large to yield effluents of the highest class.

197. It will be seen that, at Nottingham, where the soil is well adapted for the purification of sewage, the volume of sewage treated per acre was only 10,750 gallons. The results were exceptionally good, and there is little doubt that a larger volume could have been efficiently purified. At Cambridge, which has the same kind of soil and subsoil, the volume treated per acre, viz., 30,400 gallons, proved rather too large to yield an effluent of the highest class. Taking the two places together, the results may perhaps be regarded as supporting the evidence of witnesses that sewage can be treated at the rate of 30,000 gallons per acre per day on the best soils.

In other cases, where the soil is of a heavy nature and not so well adapted for the purification of sewage, the results again seem to corroborate the views of witnesses as to the volume which can be dealt with on unsuitable soils, viz., not more than 3,000 gallons per acre per 24 hours, if a good effluent has to be produced.

The total acreage of a farm must be relatively much greater when the sewage is purified by surface irrigation than when the method of filtration is employed, and a larger percentage surplus area is also desirable in the former case. We are not able to lay down any rule as to what the ratio of surplus acreage to total acreage should be, but generally speaking, a large surplus area is advisable.

It is true that the larger the total irrigable area, the greater is likely to be the working cost. On the other hand, with good management, the larger the surplus irrigable area, the better is the purification likely to be and—within certain limits—the prospect of profit.

198. The following Tables D, E, F, have been compiled, with a view to showing in some detail, the amount of purification work which was done, per unit area, at the farms which we had under observation.

The figures for strength of sewage, strength of effluent, and units of purification are arrived at on the bases already explained.

TABLE D.

Name of Farm.	Population per acre of land under treatment.	Relative figures of population per acre of land under treatment.	Gallons of sewage treated per acre of land under treatment, per day.	Gallons of sewage treated per square yard of land under treatment, per day.	Relative figures.	Relative oxidizable matter treated per square yard (*i.e.*, gallons per square yard "strength" figure for sewage).	Relative figures.	Ratio of oxidizable matter treated per unit area to volume treated per unit area.	Gallons of sewage per head per day.
Cambridge - - - - -	675	100	30,400	6·28	100	666	100	1 : 9·4	45
Altrincham - - - - -	514	76	23,000	4·75	76	259 (?)	39 (?)	—	44
Nottingham - - - - -	397	59	10,750	2·22	35	404	61	1 : 5·5	27
Beddington - - - - -	238	35	9,500	1·96	30	218	33	1 : 9·0	40
Rugby - - - - - -	171	25	8,500	1·76	28	296	46	1 : 5·8	50
Aldershot Camp - - -	166	25	8,300	1·72	27	332	50	1 : 5·2	50
Leicester - - - - - -	146	22	5,370	1·11	18	180	28	1 : 5·9	37
South Norwood - - - - -	138	20	4,000	0·83	13	61	9	1 : 13·7	29

TABLE E.

Name of Farm.	Gallons of sewage treated per square yard of land under treatment per day.	"Strength" of Sewage.	"Strength" or oxidizability of effluent (including the nitrate).	Parts by weight of oxygen used in oxidizing 100,000 parts of sewage (including the oxygen required to produce the nitrate of the effluent).	"Units of purification" effected per square yard.	Average depth to drains.	"Units of purification" effected per cube yard.	Percentage purification calculated on "Oxygen absorbed" in 4 hours from permanganate (chance effluents compared with hourly sewages).
Cambridge - - - - - - -	6·28	106 (2)	0·0	106	666	4 ft. 6 in.	381	92 per cent.
Altrincham - - - - - - -	4·75	54·5 ? (1)	4·4	50·1	238	3 ft. 9 in.	190	?
Nottingham - - - - - - -	2·22	182	5·0	187	415	7 ft. 0 in.	178	99
Beddington - - - - - - -	1·96	111	6·7	104·3	204	2 ft. 3 in.	272	89
Rugby - - - - - - -	1·76	168	7·4	160·6	283	Say 2 ft. 0 in.		92
Aldershot Camp - - - - -	1·72	193	1·0	192	330	3 ft. 3 in.	305	87
Leicester - - - - - - -	1·11	168 (2)	8·0	160	178			88
South Norwood - - - - - -	0·83	73	3·6	69·4	57·6			81

(1.) ALTRINCHAM.—In this case the "strength" is calculated from 4 *chance* samples of sewage plus 5 *chance* samples of lagoon liquor. The figure for "strength" is therefore not nearly reliable as in the other cases; probably it is considerably below the truth.

(2.) Making correction for abnormal ratio between "oxygen absorbed" from permanganate *at once* and *in 4 hours* in the cases of Cambridge and Leicester.

TABLE F.

Name of Farm.	(a) Sewage treated.	(b) Gallons per acre of land under treatment, per 24 hours ÷ 1,000	(c) Calculated strength of sewage.	(d) Relative oxidizable matter treated on unit area (b × c).	(e) Population per acre of land under treatment.	(f) Relative oxidizable matter treated per head of population (d ÷ e).
Cambridge - - -	Screened and settled.	30·4	106	3,222	675	4·8
Altrincham - -	Very well settled in lagoons.	23·0				
Nottingham - -	Screened and crude.	10·8	182	1,966	397	5·0
Beddington - -	Screened and settled.	9·5	111	1,055	238	4·4
Rugby - - -	Screened and settled.	8·8	168	1,478	171	8·6
Aldershot Camp - -	Screened and settled.	8·3	193	1,602	166	9·0
Leicester - - -	Screened and settled.	5·7	168	908	146	6·2
South Norwood - -	Screened and settled.	4·0	73	292	191	1·5

The figures in column (*f*) for relative oxidizable matter per head shew marked divergences, but still, if we except South Norwood, where the figure is probably below the truth, the extreme limits are only 4·4 and 9 or 1 : 2. The highest figures occur at Aldershot Camp and Rugby, where the sewages (domestic) are very strong.

199. The following points are brought out by these Tables :—

The *relative* figures for population per acre irrigated, and for gallons per day, follow one another pretty closely, excepting in the case of Nottingham.

The *relative* oxidizable matter per head of population varied from about 1 to 2. It was greatest in the stronger sewages.

The *relative* "strength" of the sewage per gallon, *i.e.*, oxidizable matter per gallon, varied roughly from 1 to 2½, but it was nearly constant for the less strong sewages.

The volumes of sewage (screened and settled in nearly every case) treated per 24 hours at the different farms ranged between 0·83 and 6·28 gallons per square yard, or between 4,000 and 30,400 gallons per acre.

200. The quantity of sewage which can be treated upon an unit area of land is necessarily small, because of the fineness of the filtering medium. Apart from this it is dependent upon a number of factors, of which the principal are :—

(*a*) Whether surface irrigation or filtration is followed.

(*b*) The quality and depth of the soil and subsoil.

(*c*) Whether or not the land is cropped.
(*d*) The strength of the sewage or sewage liquor.
(*e*) The degree of clarification of the liquor.

We have had no opportunity of ascertaining, quantitatively, whether it is easier with land treatment to purify one volume of strong sewage, or two volumes of a sewage of half the strength. We should infer, however, that the results with land would be so far analogous to those with artificial filters that, within ordinary limits of strength of sewage, *and so long as water-logging of the land was avoided*, there would be no appreciable difference in purification in the two cases. Since, however, a fine filtering medium like soil readily tends to become clogged on the surface, and, therefore, becomes sodden sooner than the relatively coarse medium of artificial filters, we think it would generally be found easier to treat upon land one volume of a strong sewage rather than two volumes of a sewage of half the strength, and that, therefore, with land treatment, the volume of liquid to be dealt with is of greater consequence than its actual strength.

Physical Texture of Soils.

201. A detailed account of the mechanical analyses of the soils and subsoils of the principal farms under observation is to be found in Volume IV., Part II., presented with our Fourth Report.* The results of these mechanical analyses, while too few to allow of general deductions being drawn, show that it is possible to say from the mechanical analysis of a soil whether or not it would be suitable for purifying sewage by filtration, and the same statement holds true, though in a lesser degree, as regards suitability for surface irrigation.

PRELIMINARY SETTLEMENT OF SEWAGE BEFORE LAND TREATMENT.

202. In the case of sewage which is to be treated upon artificial filters, it is generally desirable to settle out as much of the suspended solids of the sewage as possible before filtration. This is of less moment in the case of land, but where the soil is heavy we think that the sewage should usually be efficiently screened and settled. Porous sandy soils, worked as filtration farms, may be able to treat crude unsettled domestic sewage without detriment, but, even in those cases, there is the possibility of nuisance arising from the decomposition of sewage solids on the surface of the soil, and such solids may cause damage to crops.

DISPOSAL OF SLUDGE AT SEWAGE FARMS.

203. At a sewage farm the disposal of the sludge offers no particular difficulty, the land treatment of sewage possessing in this respect a great natural advantage over artificial treatment.

The question of the disposal of sludge generally is dealt with in a later section.

EVAPORATION AND ABSORPTION OF THE WATER OF SEWAGE IN LAND TREATMENT.

204. In the artificial filtration of sewage or sewage liquor, practically all the sewage which flows on to the filter appears as effluent, very little evaporation taking place. In the case of land purification, however, especially where crops are grown, the liquid is partly absorbed by the plant and partly evaporated, and consequently, the volume of the resulting effluent is materially less than that of the original sewage. Indeed, in warm weather, very little effluent passes away from surface irrigation farms treating moderate volumes of sewage.

LOSS OF NITROGEN FROM SEWAGE DURING ITS PURIFICATION.

205. The most important manurial constituent of sewage is the ammonia which is produced by the fermentation of the urea of the urine, but it also contains organic nitrogen

* Mechanical Analysis of Soils and Subsoils. By G. McGowan and R. S. Finlow.

compounds in smaller quantity, together with phosphates and salts of potash. In the process of sewage purification by artificial filtration, varying quantities of the nitrogen of the ammonia and other compounds disappear, partly, no doubt, from conversion into gaseous nitrogen, and partly from being assimilated by vegetable growths, worms, flies, etc.; the remainder of the nitrogen is converted (in a well purified effluent) into nitrate. The following average figures, obtained from our own work, may be taken as giving a fair idea of the amounts of nitrogen which disappear during the treatment of sewage and sewage liquors upon contact beds and percolating filters, and upon land. In the latter case, much of the nitrogen which has vanished has been used up by growing crops.

—	Percentage of the Nitrogen of Sewage or Sewage Liquor which disappears during the Process of Purification.
Land Surface Irrigation of Sewage - - - - - -	About 60 (40 to 75).
Land Filtration of Sewage - - - - - - -	
Treatment of Sewage on Percolating Filters - - -	40 to 50.
" Septic Liquor on Contact Beds - - -	40 to 45 Single Contact. 40 to 50 Double Contact.
" Septic Liquor on Percolating Filters - -	30 to 40 or less.
" Precipitation Liquor on Contact Beds - -	25 (Single Contact.)*
" Precipitation Liquor on Percolating Filters -	40 to 50.

206. It is in the form of nitrate that nitrogen is taken up by most plants. Much has been written about the loss to the country arising from the non-utilisation of the nitrogen of sewage which has been purified by artificial filtration, a loss which is certainly to be deplored. It is, however, frequently forgotten that when water-borne sewage is purified on land, upon which grass or other crops are grown, loss of nitrogen is, to a large extent, unavoidable in the colder seasons of the year, since plants can only assimilate nitrate very slowly in cold weather. As regards the production of nitrate in the soil, it is well known that this is largely influenced by temperature, coming practically to a standstill when the temperature is very low, but it is probable, we think, that in this country the temperature would very rarely be sufficiently low for a long period, to arrest nitrification. During our observations on sewage farms, we had no experience of a very severe winter, but nitrification was not materially hindered by such cold as we did experience. It will, of course, be remembered, in this connection, that the temperature of sewage itself is comparatively high.

In Vol. IV., Part IV., of the Report to the Commission upon Land Treatment (Engineering and Practical), by Mr. Kershaw, are diagrams giving the daily temperatures, over a year, of air, sewage, and effluent at the sewage farms of Nottingham, Aldershot Camp, South Norwood, and Beddington. On only one occasion during the winter of 1900–1 did the temperature of the sewage at Nottingham fall below 50° F., while the lowest temperatures for sewage at other farms were 46° F. at Beddington, 42° F. at South Norwood, and 40° F. at Aldershot Camp. The diagrams also show the equalising effect, as regards temperature of effluent, of the filtration farms, Aldershot Camp and Nottingham, while in the case of the surface irrigation farms of Beddington and South Norwood, the temperature of the effluent follows that of the air pretty closely.

There is, unfortunately, no economical method of extracting the nitrate from a sewage effluent otherwise than through the agency of plants, and, as we have stated, there must of necessity be a considerable loss of valuable nitrogenous manure from water-borne sewage, even in the case of land purification. In the case of artificial filtration, supposing

* This figure is from one installation only.

the effluent to be subsequently discharged into a stream, the loss is, of course, much greater, all the manurial constituents of the sewage, apart from those in the sludge, being wasted. They will, it is true, augment the vegetable growths in the stream itself, but this is nearly always more or less objectionable.

Is a Sewage Farm Dangerous to Health?

207. No proof has yet been furnished of direct or wide-spread injury to health, in the case of well-managed sewage farms. It is interesting to note here that the Report for 1905 on the sewage farm of Berlin contains the following statement:—

"We can only repeat here what we have said in previous Reports—that the sewage treatment (*Rieselbetrieb*) has had no injurious effect upon health."

This farm covers an area of nearly 39,000 acres of sandy soil, and there was on the ground in 1905 a resident population of 4,198 persons.

Wells in the Neighbourhood of Sewage Farms.

208. We have examined too few samples of well water in the neighbourhood of sewage farms to allow of our drawing any safe conclusions, on experimental grounds, as to the admissibility of such wells. But on general grounds, and quite apart from any scientific data, it would seem to be unsafe to sink any shallow wells in the neighbourhood of sewage farms, or to use water for domestic purposes from any such existing wells, unless the evidence as to the safety of the water were of a most convincing kind.

Deep wells sunk through an impermeable stratum are probably safe in the majority of instances, but wells not protected in this way, and sunk through fissured strata, can not be relied on to yield a safe water supply, however deep they may be.

Chalk wells are, perhaps, the most dangerous in this respect, and a recent Report by Dr. Copeman on an outbreak of enteric fever at Fulbourn Asylum,* and a paper † read at a recent meeting of the Epidemiological Society by Drs. Richards and Brinker, serve to confirm this view in a striking manner. The latter mention that a culture of a special organism was poured into a "swallow" hole at a distance of about two miles from the well, and was recovered from the well water after 67½ hours. It is doubtful whether sewage farms on chalk should be permitted without wide knowledge of the trend of underground water in relation to water supplies.

An attempt was made to collect an effluent on the Luton farm by digging a pit in the chalk, and in this way a few samples were obtained. The results, so far as they went, showed that *apart from the purification effected by the surface soil*, sewage underwent comparatively little purification in its passage through about three feet of chalk.

Sewage Farms on Peat Land.

209. Peat being of the nature of a sponge is not suitable for sewage purification, because of the difficulty of draining it, and the consequent lack of aeration. Some observations were made at the Worsley Sewage Farm, part of which is on peat land, and the results obtained there bear out this statement. The details of these observations are to be found in Vol. IV., Parts I. to IV., presented with our Fourth Report.

Management of Sewage Farms.

210. It is impossible to lay too much stress on the importance of sewage farms being well managed. In this connection it has to be borne in mind that farm managers have a most difficult part to play, and no amount of care and attention will ever enable land, of any kind, to deal with a volume of sewage which is in excess of the effective purifying area of the soil. We think it would be useful that farm managers should be taught some simple test or tests to enable them to follow the operations of the land; that their instructions should include a definite order to consider the farming results as quite secondary to the production of an effluent of the required standard; that the statistics of the farm should be carefully kept; and that, wherever possible, the flow of sewage and storm water should be gauged throughout the year.

As a general rule, we consider that sewage farms should not be let.

* Report of the Medical Officer, Local Government Board, 1905–6, Appendix A., No. 6, pp. 146–169.
† The Potential Danger of Water derived from Wells in the Chalk.

Some Observations as to the Cost of Land Treatment of Sewage.

211. The cost of land treatment, as in the case of artificial filtration, varies with local conditions, and no figures can be given which would be generally applicable. In Table I. we give the annual cost per 1,000,000 gallons and per head for the eight sewage farms which we had under our own observation for over two years. In each case, the cost per 1,000,000 gallons is based upon the dry weather flow of sewage. The actual flow, however, included large volumes of storm water in most cases.

Table I.

Farms which were under continuous observation by officers of the Commission for over two years.

Place.	Population draining to farm.	Dry weather flow of sewage in gallons per 24 hours.	Net cost of treating the sewage per million gallons (including loan charges), based on the dry weather flow.	Net annual cost of treatment per head of population draining to farm, including loan charges.
		Gallons.	£ s. d.	s. d.
South Norwood -	21,000	600,000	*15 9 7	*3 2½
Leicester - - -	197,000	7,250,000	5 12 8½	1 6
Croydon (Beddington)	100,000	4,000,000	5 7 5¾	1 6¾
Cambridge - -	50,000	2,250,000	2 5 5¾	0 9
Aldershot Camp -	20,000	1,000,000	†1 18 4	†0 8¼
Rugby (High Level)	6,000	300,000	1 9 8½	0 6¼
Altrincham - -	18,000	800,000	1 3 3¾	0 4¼
Nottingham - -	258,000	7,000,000	The figures of cost cannot be given for Nottingham. Excluding loan charges, cost of pumping, and rent of farm, however, there is usually a small profit on the year's working of the farm, which covers the cost of labour and also part of the rent.	

212. With a view to making some comparison between the cost of land treatment and the cost of treatment by "artificial" processes, we have thought it useful to work out the cost of treating on land a dry weather flow of 1,000,000 gallons a day, in certain hypothetical cases, following the plan adopted in regard to filters.

It is assumed for the purpose of this comparison :—

That, in the case of surface irrigation, sufficient fall is available, and that, in the case of filtration, the land is fairly level, admitting of its being used without abnormal expenditure in levelling and grading.

That the sewage to be treated is of a normal domestic character and of average strength (*i.e.*, gives a *four hours* "oxygen absorbed" figure of 10 to 12 with strong permanganate, and requires about 100 parts by weight of oxygen for the complete oxidation of 100,000 parts).

That the flow of sewage is one million gallons per day in dry weather.

That the district is sewered on the combined or the partially separate system.

That the cost of the land is £100 per acre.

*These figures include cost of pumping the effluent from the lower to the higher portions of the farm.

† No loan charges in the case of Aldershot Camp.

The soils and subsoils which we have considered, may be divided into the following three broad classes :—

Class I. All kinds of good soil and subsoil, *e.g.*, sandy loam overlying gravel and sand as at Nottingham, Cambridge, and Beddington.

Class II. Heavy soil overlying clay subsoil, as at Rugby.

Class III. Stiff clayey soil overlying dense clay, as at Leicester and South Norwood.

Since variations exist in practice, both as regards the method of purification employed and the extent of cropping, the first of these three classes may be divided into three sub-classes, as follows :—

Class I.
- Sub-class a. Filtration with cropping.
- Sub-class b. Filtration with little cropping.
- Sub-class c. Surface Irrigation with cropping.

The method of purification assumed for the other classes of soil are :—

Class II. Surface Irrigation with cropping.

Class III. Surface Irrigation with cropping. With a heavy soil and clay subsoil, by far the greater part of the purification is effected by surface irrigation, though in exceptional circumstances, such as obtain at Leicester, a good deal is also done by filtration.

213. Having regard to the volume of sewage dealt with and the purification effected at the farms which were kept under our own observation, and the evidence given by various witnesses, we estimate that the several classes of soil and subsoil could effectively deal with the volumes of settled sewage given in Table II.

Table II.

Class of soil and subsoil, and method of working.	Volume of settled sewage which can be dealt with per acre per 24 hours.	Total area of land required to deal with a dry weather flow of one million gallons.*
Class I. Sub-class a. Filtration with cropping -	12,000 gallons	84 acres
Class I. Sub class b. Filtration with little cropping	25,000 gallons	40 acres
Class I. Sub-class c. Surface irrigation with cropping	7,000 gallons	145 acres
Class II. Surface irrigation with cropping - -	5,000 gallons	200 acres
Class III. Surface irrigation with cropping - -	3,000 gallons	334 acres

* These areas are sufficient for the treatment in times of storm water of three times the mean dry weather flow.

Preliminary Tank Treatment.

214. At many of the sewage farms named in Table I. there is no preliminary settlement of the sewage, while at some of them the preliminary process does not secure anything like complete removal of the suspended matter.

For the purpose of our comparison, however, we have assumed preliminary settlement of the sewage in tanks of the capacities indicated in Table III:—

TABLE III.

Class of soil and subsoil and method of working.	Average stay in tanks.	Total number of tanks.	Number of spare tanks.	Total capacity of tanks (gallons)	Constructional cost of tanks.*
Class I. Sub-class a. Filtration with cropping	4½ hours	4	1	250,000	£2,230
Class I. Sub-class b. Filtration with little cropping	4½ hours	4	1	250,000	£2,230
Class I. Sub-class c. Surface irrigation with cropping	4½ hours	4	1	250,000	£2,230
Class II. Surface irrigation with cropping	15 hours	8	2	833,333	£5,112
Class III. Surface irrigation with cropping	15 hours	8	2	833,333	£5,112

* The estimates of the constructional cost of tanks are strictly comparable with the estimates for similar plant in connection with the artificial processes, and have been obtained by preparing drawings and taking out quantities.

Cost of Preliminary Tank Treatment and Disposal of Sludge.

215. We estimate that the working of the tanks and the disposal of the sludge, including trenching the land and covering the sludge, would require the services of two men for each of the first three classes (4½ hours sedimentation), and the services of three men for the other two (15 hours sedimentation).

Taking labourers' time at 21s. per week, and including one-third of the manager's time at a salary of £130 per annum, the following figures are obtained:—

TABLE IV.

Class of soil and subsoil and method of working.	Labour and supervision in connection with tanks and disposal of sludge. Per annum.	Per million gallons of sewage (dry weather flow).
	£	s. d.
Class I. Sub-class a. Filtration with cropping	152	8 4
Class I. Sub-class b. Filtration with little cropping	152	8 4
Class I. Sub-class c. Surface irrigation with cropping	152	8 4
Class II. Surface irrigation with cropping	208	11 5
Class III. Surface irrigation with cropping	208	11 5

In the case of Classes II. and III. (heavy soils and subsoils), it would generally be advisable to eliminate the suspended solids from the sewage to a greater extent than in the other class where the soil and subsoil are of good quality.

With an average domestic sewage, the suspended solids after 4½ hours settlement (continuous flow) would be about 20 to 25 parts per 100,000, and, after a 15 hours settlement (continuous flow), from 10 to 15 parts per 100,000.

Converting these amounts of suspended solids into tons of wet sludge per million gallons, the quantities of sludge to be disposed of are approximately as follows:—

TABLE V.

Class of soil and subsoil and method of working.	Wet sludge (90% water) produced per million gallons from the average daily flow.	Area of land estimated to be required for disposal of the sludge.
Class I. Sub-class a. Filtration with cropping	8 to 10 tons	5 acres
Class I. Sub-class b. Filtration with little cropping	8 to 10 tons	5 acres
Class I. Sub-class c. Surface irrigation with cropping	8 to 10 tons	5 acres
Class II. Surface irrigation with cropping	17 to 20 tons	12 acres
Class III. Surface irrigation with cropping	17 to 20 tons	20 acres

Table VI. shows the total areas of land required for treatment of the sewage and for disposal of the sludge, and the total cost of land and tanks.

TABLE VI.

Class of soil and subsoil.	Total area of land required to treat a dry weather flow of one million gallons.	Area of land required for disposal of sludge.	Total area.	Total cost of land at £100 per acre.	Cost of laying out land, including levelling, grading, underdrains, carriers, etc.	Cost of tanks.	Total cost.
				£	£	£	£
Class I. Sub-class a	84 acres	5 acres	89 acres	8,900	6,334	2,230	17,464
Class I. Sub-class b	40 acres	5 acres	45 acres	4,500	4,589	2,230	11,319
Class I. Sub-class c	145 acres	5 acres	150 acres	15,000	4,494	2,230	21,724
Class II.	200 acres	12 acres	212 acres	21,000	5,770	5,112	32,082
Class III.	334 acres	20 acres	354 acres	35,400	7,599	5,112	48,111

216. With regard to the underdraining of land, the necessity for drains depends not merely upon the nature of the soil and subsoil, but upon the volume of liquid dealt with per acre. A porous soil and subsoil like that at Beddington can be made to answer perfectly well without underdrains, when a moderate volume of sewage is applied; when, however, a large volume is applied, underdrains are necessary, in order to assist the land to "dry-off" sufficiently rapidly.

In Sub-class a (Class I.), we have assumed that the tributary drains average 6 feet in depth and are laid 66 feet apart.

In Sub-class b (Class I.), where the volume of liquid applied is larger, and the area proportionately less, the tributary drains, also 6 feet deep, have been placed 50 feet apart.

In the case of the surface irrigation farms (Sub-class c and Classes II. and III.), underdrainage has been allowed for, to provide for the contingency of possible over sewaging of the plots; but in the case of the heavy soils and subsoils we have assumed that the drains are only laid at a depth of 2 feet 6 inches and that they are brought to the surface of the ground to admit of re-treatment of the effluent by surface irrigation.

Loan Charges.

217. Table VII. gives the loan charges in respect of cost of land, tanks, etc., on the basis of loans raised for thirty years, at 3½ per cent. interest per annum.

TABLE VII.

Class of soil and subsoil and method of working.	Loan charges in respect of land, tanks, laying out land, underdrains, etc.	
	Per annum.	Per million gallons of sewage. (dry weather flow).
	£ s. d.	£ s. d.
Class I. Sub class a. Filtration with cropping	949 12 1	2 12 0
Class I. Sub-class b. Filtration with little cropping	615 9 5	1 13 8¼
Class I. Sub-class c. Surface irrigation with cropping	1,181 4 10	3 4 8¾
Class II. Surface irrigation with cropping	1,744 9 2	4 15 7
Class III. Surface irrigation with cropping	2,616 0 8	7 3 4

Labour in connection with the Distribution of the Sewage.

218. The number of men required in connection with the distribution of the sewage, etc., must of course depend largely upon the nature and contour of the lands sewaged, and upon the nature of the crops raised, whether stock is kept, etc.

From numerous examples of land treatment, however, we find that roughly speaking one man can attend to the distribution of the sewage over about 40 acres.

It has been assumed in the present comparison that the services of the men who undertake the sludging of the tanks are available, and we estimate that in addition to these men the number of watermen required would be as follows:

TABLE VIII.

Class of soil and subsoil and method of working.	Number of watermen required.
Class I. Sub class a. Filtration with cropping	One.
Class I. Sub-class b. Filtration with little cropping	One.
Class I. Sub-class c. Surface irrigation with cropping	Two.
Class II. Surface irrigation with cropping	Three.
Class III. Surface irrigation with cropping	Four

Taking labourers' wages as before at 21s. per week, together with two-thirds the manager's time, the cost of labour and supervision in respect of the distribution of sewage is as follows:—

TABLE IX.

Class of soil and subsoil and method of working.	Cost of labour and supervision in respect of distribution of sewage.	
	Per annum.	Per million gallons (dry weather flow).
	£	£ s. d.
Class I. Sub-class a. Filtration with cropping	141	0 7 8¾
Class I. Sub-class b. Filtration with little cropping	141	0 7 8¾
Class I. Sub-class c. Surface irrigation with cropping	196	0 10 9
Class II. Surface irrigation with cropping	250	0 13 8¼
Class III. Surface irrigation with cropping	305	0 16 8¼

219. The total cost of treatment, including loan charges and all other charges, is shown in Table X.

TABLE X.

Total Gross Cost of Land Treatment.

Class of soil and subsoil and method of working.	Per annum.	Per million gallons (dry weather flow).
	£ s. d.	£ s. d.
Class I. Sub-class a. Filtration with cropping	1,242 12 1	3 8 0¾
Class I. Sub-class b. Filtration with little cropping	908 9 5	2 9 9
Class I. Sub-class c. Surface irrigation with cropping	1,529 4 10	4 3 9¾
Class II. Surface irrigation with cropping	2,202 9 2	6 0 8½
Class III. Surface irrigation with cropping	3,129 0 8	8 11 5½

Returns from Sales of Crops.

220. In the case of land treatment of sewage, a part, frequently a large part, of the cost of treatment is defrayed by returns from sales of crops, stock, sludge, etc.

These returns necessarily vary at different farms, but we find from a careful study of the figures obtained at thirteen sewage farms, that the net return, after deducting cost of agricultural working, may be put at about 30s. per acre of the total area of the farm. We have therefore taken this figure for our calculations in the following Table:—

TABLE XI.

Class of soil and subsoil and method of working.	Returns from sales of crops.	
	Per annum.	Per million gallons (dry weather flow).
	£ s. d.	£ s. d.
Class I. Sub class a. Filtration with cropping	126 0 0	0 6 10¾
Class I. Sub-class b. Filtration with little cropping	60 0 0	0 3 3¼
Class I. Sub-class c. Surface irrigation with cropping	217 10 0	0 11 11
Class II. Surface irrigation with cropping	300 0 0	0 16 5
Class III. Surface irrigation with cropping	501 0 0	1 7 5

Total net Cost of Treatment.

221. Deducting the returns from sales of crops from the gross cost of treatment, we obtain the following figures for the total net cost of treatment:—

TABLE XII.

Class of soil and subsoil and method of working.	Net cost of treatment.	
	Per annum.	Per million gallons.
	£ s. d.	£ s. d.
Class I. Sub-class a. Filtration with cropping	1,116 12 1	3 1 2
Class I. Sub class b. Filtration with little cropping	848 9 5	2 6 6
Class I. Sub-class c. Surface irrigation with cropping	1,311 14 10	3 11 10¾
Class II. Surface irrigation with cropping	1,902 9 2	5 4 3
Class III. Surface irrigation with cropping	2,628 0 8	7 4 0

COMPARATIVE COST OF TREATMENT OF SEWAGE BY LAND AND BY ARTIFICIAL PROCESSES.

222. Table XIII. shows the comparative cost of treatment of sewage by land and by artificial processes.

We wish to emphasize the fact that in the preparation of our "cost" tables, we have made a number of assumptions. and that the relative cost of different methods would, in practice, largely depend on local circumstances.

TABLE XIII.

	Total cost of treatment per annum.	Total cost of treatment per million gallons.	*Cost per head of population draining to works (population taken at 30,000).
Method of Treatment.	PERCOLATING	FILTERS.	
	£ s. d.	£ s. d.	s. d.
Chemical precipitation, quiescent settlement, followed by percolating filters.	1,831 0 4	5 0 4	1 2½
Chemical precipitation, continuous flow settlement, followed by percolating filters.	1,796 11 2	4 18 5	1 2¼
Quiescent settlement, followed by percolating filters.	1,490 16 11	4 1 7	0 11¾
Continuous flow settlement, followed by percolating filters.	1,525 1 1	4 3 7	1 0
Septic Tanks, followed by percolating filters	1,589 13 4	4 7 2	1 0½
	CONTACT	BEDS.	
Chemical precipitation, quiescent settlement, followed by single contact beds.	2,058 16 11	5 12 10	1 4¼
Chemical precipitation, continuous flow settlement, followed by double contact beds.	2,314 12 5	6 6 9	1 6½
Quiescent settlement, followed by double contact beds.	2,398 0 7	6 11 4	1 7
Continuous flow settlement, followed by double contact beds.	2,596 17 3	7 2 3	1 9
Septic Tanks, followed by double contact beds	2,661 9 6	7 5 10	1 9¼
Class of soil and subsoil and method of working.	LAND TREATMENT.		
Class I. Sub-class a. Filtration with cropping	1,116 12 1	3 1 2	0 8¾
Class I. Sub-class b. Filtration with little cropping	848 9 5	2 6 6	0 6¾
Class I. Sub-class c. Surface irrigation with cropping	1,311 14 10	3 11 10¾	0 10½
Class II. Surface irrigation with cropping	1,902 9 2	5 4 3	1 3¼
Class III. Surface irrigation with cropping	2,628 0 8	7 4 0	1 9

*Based on a flow of 33 gallons of sewage per head per day.

Assuming that really suitable land can be purchased at £100 per acre, land treatment of sewage is probably cheaper than artificial treatment, but where the soil is not suitable, and on which only a comparatively small volume of sewage can be treated per acre, the cost of land treatment would probably be greater than most of the artificial processes.

The differences in cost are, however, small, and it is evident that, in deciding between the two methods, regard must be had to local conditions. If, for instance, £200 per acre had to be paid for land, the cost of land treatment would materially exceed the estimates given, which have been based on an assumed uniform price of £100 per acre.

As a general rule an effluent from good land, properly worked, contains practically no suspended solids, but this cannot be said of artificial filters, even assuming that settlement of the effluent in tanks is adopted. This might be a factor of considerable importance in the case of some streams.

The figures of cost in this section have been prepared by our Engineer, Mr. G. B. Kershaw.

PART IV.—SLUDGE.

DISPOSAL OF SEWAGE SLUDGE.

223. The disposal of sewage sludge, whether it is produced by settlement after chemical precipitation, settlement without chemicals, or septic tank treatment, is one of the chief difficulties in dealing with sewage, especially in the case of large towns or cities. Probably it will always remain so, excepting at small sewage works, for although sewage sludge contains small quantities of nitrogenous compounds and phosphates, and sometimes grease in sufficient quantity to repay extraction, by far the greater part of it consists, in addition to moisture, of mineral matters, together with some cellulose.

Conversion of Sludge into a Marketable Manure.

224. Two processes for converting sludge into a marketable manure have been under observation by us, viz.:—the production of "Native Guano" by the Native Guano Company, Limited, at Kingston-on-Thames, and the production of "Globe Fertilizer" by Mr. Melvin's process at Glasgow.

KINGSTON-ON-THAMES.

At Kingston a quantity of alumino-ferric, together with blood, charcoal, and clay is added to the sewage. This mixture acts as an extremely efficient precipitant, producing uniformly, from a sewage of about average strength, a tank liquor containing seldom more than two parts of suspended matter per 100,000. The sludge is removed from the tanks, pressed, partially dried by heat and sieved, and, after further air-drying during storage, is sold under the name of "Native Guano." The cost to the inhabitants of Kingston of the precipitation of the sewage and the disposal of the sludge * is 1s. 8d. per head per year. This is considerably less than it would be if a less expensive precipitation process were adopted and the sludge barged to sea. Further, although there is generally a slight peculiar odour of Native Guano upon the works, the treatment, so far we have observed it, has been free from nuisance.

It will be seen from the manurial experiments with sewage sludges, which are referred to later, and which were carried out for the Commission through the Board of Agriculture and the Royal Agricultural Society, during the seasons 1905–7,† that unit for unit the nitrogen and phosphate of the Native Guano were less effective, at all events within the limits of one season, than the same constituents applied in the form of ordinary artificial manure. Judged solely in this light, the price of the Native Guano is in excess of its direct manurial value. On the other hand, the books of the Company show that the manure is sold to the same farmers year by year. The manure appears to be used to a considerable extent for flower culture.

We doubt whether the process could be worked as a financial success if it were adopted at a *large* number of places, as, apart from the considerations which have just been mentioned, a greatly increased production of the manure would, we think, be certain to lower the price considerably.

It should be added, however, that the cost of the precipitation, and possibly also of other parts of the manufacture of the Native Guano, might, we think, be materially reduced by working on a large scale.

* This constituted the whole process at Kingston during the greater part of our observations. The figure 1s. 8d. per head refers to the precipitation and sludge disposal only. The precipitation liquor is now (1907) treated upon filters.

† Reports upon Experiments with various kinds of Sewage Sludges, as applied to mangolds, grass and cereals, by Dr. W. Somerville (1906), Mr. T. H. Middleton (1907), and Dr. J. A. Voelcker (1907), Appendix VIII.

A sample of Native Guano (A.), made up of eighty-five different fractions, was taken on March 23rd, 1905, and examined both chemically and bacteriologically. It was in a fine state of division. In the second column are given the figures of analysis of another sample of Native Guano (B.), examined partly in October, 1904, and partly in January, 1905. The following results were obtained :—

	A. Per cent.	B. Per cent.
Moisture (at about 110° C.)	25·87	10·19
Matter volatile on ignition	37·99	45·08
Non-volatile matter	36·14	44·73
	100·0	100·0

Analysis of Non-Volatile Matter.

	Per cent.	Per cent.
Grit (*i.e.*, matter insoluble in hydrochloric acid, after ignition)	22·33	28·04
Oxides of iron and alumina*	10·10	11·59
Lime†	3·30	4·78
Magnesia		0·42
Potash (soluble in dilute hydrochloric acid)	approx. 0·16	—
Potash (soluble in water)	0·06	—
Phosphoric acid (P_2O_5)	1·74§	2·35§
Equivalent to tribasic phosphate of lime	3·30	5·13
Yield of Nitrogen (total)	1·93‖	2·49‖
Nitrogen evolved as ammonia on boiling for 2 hours with a dilute solution of potash (0·5 per cent. KOH)	0·41	0·50

Allowing for the difference in moisture, the above two samples have almost the same composition, but B. is slightly richer in nitrogen and phosphoric acid than A.

Bacteriological Analysis.—Sample A.

Kingston "Native Guano." Average of eighty-five samples, March 23rd, 1905.

B. Coli Test.—Negative result with 1 gramme.

Neutral Red Broth Test.—As regards fluorescence, positive with 1-1,000; negative with 1-10,000 of a gramme. Growth in tube inoculated with 1-10,000,000,000 of a gramme, indicating the survival of an enormous number of bacteria.

B. Enteritidis Sporogenes Test.—Positive result with 1-1,000; negative with 1-10,000 of a gramme.

GLASGOW (DALMARNOCK).

225. Mr. Melvin's process at Glasgow for the production of the "Globe Fertiliser" is somewhat similar to the process for the production of Native Guano. The sludge is produced from the Glasgow (Dalmarnock) sewage by precipitation with lime and ferric sulphate. After removal from the tanks it is pressed, and that part of it which is to be converted into Globe Fertiliser is then artificially dried at a temperature of about 65° to 70° C., and finally passed through a pan-mill. It issues from the latter as a moist brown powder, which is given the name of "Globe Fertiliser." An average sample of this, collected on April 6th, 1905, gave the following figures on analysis :—

	Per cent.
Moisture (at about 110° C.)	22·51
Matter volatile on heating	33·98
Non-volatile matter	43·51
	100·0

* These oxides will contain the phosphoric acid and possibly a very little of the lime.

† The lime was precipitated only once; it will contain traces of magnesia.

§ ‖ The figures for phosphoric acid and for total nitrogen are in each case the mean of two closely agreeing estimations.

Analysis of Non-Volatile Matter.

	Per cent.
Grit, etc. (*i.e.*, matter insoluble in hydrochloric acid, after ignition)	10·75
Oxides of iron and alumina*	13·42
Lime†	12·09
Magnesia	—
Potash (soluble in hydrochloric acid)	approx. 0·10
Phosphoric acid (P_2O_5)	1·11‡
Equivalent to tribasic phosphate of lime	2·42
Yield of Nitrogen (total)	1·30‖
Nitrogen evolved on boiling the sludge for 2 hours with dilute (0·5 per cent.) potash solution on May 22nd [1]	0·06

([1] Grey mould on surface, at this date, which was avoided in sampling).

Bacteriological Analysis.

Glasgow, "Globe Fertiliser." Average of twenty samples.

B. Coli Test.—Negative result with 1 gramme.

Neutral Red Broth Test.—As regards fluorescence, positive result with 1-1,000; negative with 1-10,000 of a gramme. Growth in 1-100,000; no growth in 1-1,000,000 of a gramme.

B. Enteritidis Sporogenes Test.—Positive result with 1-100; negative with 1-1,000 of a gramme.

A larger portion of the sludge is converted into pressed cake, without being artificially dried.

The following table shows the production and sale of Globe Fertiliser and pressed cake at the Glasgow (Dalmarnock) works during the five years ending March, 1907 :—

AGGREGATE QUANTITIES OF 5 YEARS' WORKING.

Total amount of wet sludge dealt with. (Tons).	Total amount of pressed cake produced. (Tons).	Total amount of pressed cake sold to farmers. (Tons).	Total amount of Globe Fertiliser produced. (Tons).	Total amount of Globe Fertiliser sold to Customers. (Tons).
1,104,297 (Moisture 91% approx.).	177,566 (Moisture 60 to 65%).	124,883	5,702	5,703

Mr. Melvin gives the costs relating to these figures (excluding interest and sinking fund), as follows :—

Cost of pressing alone, per ton of pressed cake.—2s. $0\frac{5}{10}$d.

Cost of production of Globe Fertiliser, approximately.—5s. 6d. per ton, excluding pressing of wet sludge.

Total cost of production of Globe Fertiliser, approximately.—10s. per ton.

The average price obtained for the pressed cake was 8d. to 1s. per ton in bulk; the average price for the Globe Fertiliser 8s. to 10s. per ton in bulk, or 14s. per ton in bags. The purchaser pays the carriage in all cases.

* These oxides will contain the phosphoric acid and possibly a very little of the lime.

† The lime was precipitated only once; it will contain traces of magnesia.

‡ ‖ The figures for phosphoric acid and for total nitrogen are in each case the mean of two closely agreeing estimations.

The analyses of the pressed cake and Globe Fertiliser are given by Mr. Melvin as follows :—

	Pressed Cake. Per Cent.	Globe Fertiliser. Per Cent.
(1) Organic Matter	13·84	35·20
(2) Mineral Matter	18·16	46·20
Moisture	68·00	18·60
	100·0	100·0
(1) Containing Nitrogen	·52	1·34
Equal to Ammonia	·64	1·63
Or Sulphate of Ammonia	2·49	6·33
(2) Containing Phosphoric Acid	·54	1·39
Equal to Tribasic Phosphate of Lime	1·19	3·03
Analysis Value	6s. 11d. per ton.	17s. 8d. per ton.

It will be seen, therefore, that at Dalmarnock, by careful organisation and advertising, practically the whole of the sludge is disposed of by sale, either as pressed cake or as Globe Fertiliser, the cost of the sewage treatment being in this way materially reduced. The saving effected is about 4s. per 1,000,000 gallons. During the three years ending March 31st, 1907, the whole of the pressed cake was sold to farmers. The demand is still increasing and the connection is now good enough to obviate the necessity for advertising.

Mr. Melvin states that it is more convenient to sell sludge as pressed cake than as Globe Fertiliser, partly because less work is entailed in the former case, and partly because in the manufacture of the Fertiliser much dust is produced, and he finds it difficult to get his men to wear respirators. For this reason, the Globe Fertiliser is now made during spring and autumn only, and the quantity is diminishing year by year.

In comparing the sale of pressed cake at the Dalmarnock works with sales and possibilities of sales elsewhere, it has to be specially noted that there is a branch line of railway into the Dalmarnock works, and therefore no carting is required.

Disposal of Sludge by Depositing at Sea.

226. There can be little doubt that, for cities on or near the sea-board, the disposal of sludge by taking it to sea is, in the majority of cases, the cheapest process.

Except, however, in the case of the Barrow Deep, where the London sludge is discharged, little attention appears to have been paid to the effect of the sludge upon the character of the water in the neighbourhood of the dumping area. In order to avoid nuisance and possible danger to health from the pollution of shell-fish, periodical examination of the local conditions is generally desirable wherever this method of disposal is adopted.

London.

et seq. Report, 227. The plan adopted for the disposal of the London sludge was fully explained to us by Mr. M. Fitzmaurice, C.M.G., when giving evidence on July 14th, 1903.

It will be seen from the evidence that the sludge is deposited at the Barrow Deep, over a length of from five to ten miles.

The Barrow Deep is practically the open sea, being situated about 20 miles below Southend.

The following table, which has been more recently supplied to us by Mr. Fitzmaurice, shows the quantity of wet sludge, etc., deposited in the Barrow Deep during the years 1903, 1904, 1905 and 1906 :—

County of London.

Year.	Average daily quantity of sewage dealt with. (Gallons.)	Total quantity of sludge produced at Barking and Crossness. (Tons.)	Average percentage of moisture in the sludge.	Total quantity of sludge sent to sea (Tons.)	Number of trips made by the steamers.	Total cost of sending to sea, per ton of wet sludge, interest, sinking fund, steamer dues, cost of filling ships and all charges included.†
1903	259,769,466	2,563,000*	92·02%	2,563,000*	2,563	4·51d.
1904	250,590,204	2,530,000	92·28%	2,530,000	2,530	4·77d.
1905	250,698,649	2,578,000	92·16%	2,578,000	2,578	4·40d.
1906	252,882,247	2,465,000	91·95%	2,465,000	2,465	4·53d.

The average cost of sending the London sludge to sea during the years 1903 to 1906 inclusive, including interest, sinking fund, cost of filling ships, labour, fuel, repairs and all charges, was thus 4·55d. per ton of sludge containing on the average 92·1 per cent. of moisture.

228. At our request Mr. Fitzmaurice carried out some float experiments in the Barrow Deep during spring and neap tides in September, 1903. These experiments showed that, with the exception of a slight set towards the Maplin Sands at flood tide, both the ebb and the flow took a course directly along the Barrow Deep. We note, however, that floats started at the most westerly point at which the steamers begin to discharge sludge were carried back on the flood tide nearly as far as the Nore Lightship. The experiments are shown graphically in the Fourth Report of the Commission, Vol. II., p. 106.

With regard to the condition of the water in the Barrow Deep, we may refer to the evidence of Professor F. Clowes, D.Sc., F.I.C. As the result of the examination of four series of samples collected in the Barrow Deep, Dr. Clowes makes the following *Statement of Conclusions* :— Clowes, 1

"A study of these tables shows that there are on an average over 100,000,000 "of bacteria per cubic centimetre in the sludge discharged by the Council's steamers "in the Barrow Deep, and that about half this number are probably of intestinal "origin, since they are capable of growing at blood heat (37° C.); but that "immediately after the discharge of the sludge the number in the water of the "Barrow Deep is less than 2,500 per cubic centimetre, and that the number of "intestinal bacteria is generally less than 10 per cubic centimetre; indicating a "reduction of about 99·9 per cent. in the total number of bacteria and of intestinal "bacteria. Further, that the number of bacteria in the water which is carried out "of the Barrow Deep towards the mouth of the Thames, by an incoming flood tide, "is still further reduced to an average of 440 per cubic centimetre, and that the "number of intestinal bacteria has also further decreased."

The results of two experiments by Dr. Clowes upon the effect of sea water on bacterial life appear, so far as they go, to indicate that sea water does not exercise any marked inhibitory effect upon the life of the bacteria. On this showing, therefore, the above decrease in the number of bacteria in the Barrow Deep must evidently be looked upon as due to mere dilution of the sludge with sea water.

* The quantity of sludge produced per annum may be slightly different from the quantity sent to sea per annum, as a certain amount of sludge is sometimes in store at the end of one year but not sent to sea until the beginning of the following year. This difference is not shown in the above table.

† The cost of filling the ships with sludge cannot be stated separately.

Examination of the Sands in the Barrow Deep and the Thames Estuary.

Clowes 18,636. 229. In August, 1899, Dr. Clowes made a chemical and microscopical examination of samples from the sea bottom in the part of the estuary where the sludge is deposited, and in parts of it which might be affected by the sludge. His conclusions are given as follows :—

> "The results of these examinations of the sands and of the deposits in the "Barrow Deep and in other channels in the estuary of the River Thames, during "the period 2nd to 12th August, 1899, show that no sludge is carried by the tide "beyond the limits of the Barrow Deep and the Oaze Deep in a westerly or "up-river direction. The sludge which is carried in an easterly or seaward "direction must meet with so great a volume of sea water that it is quickly broken "up into innocuous bodies, and thus prevented from travelling beyond the Barrow "Deep. Accordingly no evidence of pollution by sludge was obtained in an "easterly, northerly, or southerly direction."

The subject of sea water in relation to bacteriological life is more complicated than would appear at first sight, and before conclusions can be drawn with confidence as to the effects of deposition of sludge, observations extending over a lengthened period and under a variety of conditions would, we think, be required.

Taken in conjunction with Mr. Fitzmaurice's float experiments, the above results furnish grounds for the presumption that the polluted water is for the most part carried out to the open sea on the ebb tide; but conclusively to prove that none of it returns with the flood, extensive experiments covering the whole area of the Thames estuary would be necessary.

Glasgow.

230. There are at present (1907) two outfall works at Glasgow—the Eastern or Dalmarnock outfall and the Western or Dalmuir outfall. As has previously been said, the whole of the sludge at Dalmarnock is pressed and disposed of to farmers, either as pressed cake or as Globe Fertiliser. At Dalmuir, with the exception of the grit from the catch pit and the screenings of the sewage, both of which are mostly disposed of by sale to farmers at a price of about 8d. to 1s. per ton., plus railway carriage, the whole of the sludge is taken by the s.s. "Dalmuir," and discharged in about 80 fathoms of water some three miles below Garroch Head, a distance of about forty miles from Glasgow.

The following figures, which have been supplied to us by Mr. Thomas Melvin, relate to the disposal of sludge at Dalmuir for the three years subsequent to the opening of the works in May, 1904 :—

Aggregate Quantities for the 3 Years Ending March 31st, 1907.

Total quantity of sludge produced by precipitation. (Tons).	Average percentage of moisture.	Total quantity deposited at sea. (Tons).	Average number of journeys made per annum by the s.s. "Dalmuir."	Average cost of sending sludge to sea, including all charges except interest and sinking fund and cost of filling ships, per ton of wet sludge.	Average cost, per ton of wet sludge, of handling the sludge after it leaves the precipitation tanks, *i.e.*, the cost of filling the ship.*
915,689	86·81%	915,689	268	$2\frac{5}{10}$ d. full.	$0\frac{9}{10}$ d. full.

The cost of sending the sludge to sea during the year 1906–7, including the cost of filling the ships and the interest and sinking fund for the same period, was $5\frac{4}{10}$d. per ton, for 349,492 tons of sludge containing 85·54 per cent. of moisture. This includes interest and sinking fund on a specially constructed dock, as well as upon the steamer. The loan for the dock and the steamer is repayable, however, in equal instalments extending over the long period of sixty years. If it were repayable in thirty years, the above cost would be approximately $6\frac{2}{10}$d. per ton.

*This includes the cost of fuel for the electrically driven pumps which lift the sludge into the overhead reservoir tank.

Through the courtesy of the Glasgow City Corporation one of our officers was enabled to witness the discharge of sludge into the sea on November 20th, 1907. When the steamer reached a position about 3 miles S.S.W. of Garroch Head, between the Island of Arran and the mainland, the engines were stopped, and while the steamer continued to move slowly, she was turned so as to describe a half-circle of about ¼ of a mile in diameter. All the sludge valves were open during this time (about five minutes), the whole of the sludge being thus discharged. From the bridge of the steamer the sludge could be seen just below the surface of the clear water as a thick brown cloud. It rose to the surface behind the steamer, appearing from a distance as a band of smooth water some 20 or 30 yards wide. Many thousands of gulls which had followed the steamer immediately settled upon this. On turning and passing through the sludge band, after about eight minutes had elapsed since the steamer first began to discharge, it was seen that the band had widened considerably; and after 15 to 20 minutes, during which another turn was made, the sludge was still easily visible, though more disseminated. Probably it disappears entirely in the space of half-an-hour. The impression produced on the observer was that, even with the small tide of two knots an hour, everything but the very heavy solids would be spread over a very large area before reaching the bottom. The depth of the water was about 76 fathoms. We were informed that the tides run straight up and down the Firth, part of the incoming tide flowing between Bute and Little Cumbrae and part turning to the left towards Kilbrennan Sound. No analyses of the water in the neighbourhood of the dumping area have been made by the Local Authorities. We were told that the water in the neighbourhood of the dumping area is a favourite fishing ground.

Manchester.

231. The sludge produced at the Manchester sewage works (Davyhulme) is taken by steamer through the Manchester Ship Canal and deposited in deep water outside the North-west lightship. The lightship is situated in the open sea some 12 miles north of Rhyl and about 25 miles north-west of Liverpool.

The following figures, relating to the disposal of the Manchester sludge during the past five years, have been supplied to us by the Rivers Department of the City of Manchester.

Year ending March 31st.	Nature of sludge.	Total quantity of wet sludge produced. (Tons).	Total quantity of wet sludge sent to sea. (Tons).	Average percentage of moisture in the sludge.	Number of trips made by the steamer.	Total Sea Cost :— Excluding interest and sinking fund charges, and also cost of filling ship.		Total Sea Cost :— Including interest and sinking fund charges (on steamer), but excluding cost of filling ship.‡	
						Per annum.	Per ton of wet sludge.	Per annum.	Per ton of wet sludge.
1903	Chemical precipitation (mainly) and septic tank sludge	223,100	223,100	—	181	£5,283	5·7d.	£7,273	7·8d.
1904	Chemical precipitation and septic tank sludge	157,100	157,100	*85·0	129	£4,366	6·6d.	£6,356	9·7d.
†1905	Sedimentation and septic tank sludge	148,100	143,800	*85·4	123	£3,994	6·7d.	£5,984	10·0d.
†1906	Do.	155,800	142,200	86·1	136	£4,976	8·4d.	£6,966	11·8d.
†1907	Do.	181,600	176,300	86·7	163	£4,758	6·5d.	£6,748	9·2d.
	Total for 5 years		842,500			Average	6·7d.	Average	9·5d.

* Percentage of water in septic tank sludge only.

† During these years the sludge steamer also ran on behalf of the Salford Corporation, making the following additional number of journeys :—1905, 44; 1906, 36; 1907, 25.

‡ Cost of filling ship, including sludge tank attendant, ejector attendant, repairs to ejector, and also including steam production, engines, and interest and sinking fund charges :—
Average—£123 per annum = 0·14d. per ton of wet sludge.

SALFORD.

232. The sludge from the Salford Corporation Sewage Works at Weaste is also sent through the Manchester Ship Canal and deposited outside the North-west lightship. The following figures, which have been supplied to us by Mr. J. Corbett, the Borough Surveyor, relate to the disposal of the Salford sludge for the years 1902–6 inclusive:—

Year.	Total quantity of sewage dealt with. (Gallons).	Total quantity of sludge produced and sent to sea. (Tons).	Average percentage of moisture in the sludge.	Number of journeys made by steamer.	Total cost, per ton of wet sludge, of sending to sea, including interest and sinking fund, canal dues, cost of filling ship and all other charges.
1902	3,802,182,451	129,000	80·2	215	
1903	3,989,619,000	135,000	78·6	225	
1904	3,335,080,548	134,900	79·5	199	
1905	3,782,877,000	134,900	75·4	184	
1906	4,227,950,000	145,400	81·0	191	
			Average for the five years		9·46d. per ton.

NOTE.—The percentage of water in the Salford sludge was exceptionally low during the years in question, owing partly to the fact that some old air-dried sludge which had accumulated on the works was mixed with the fresh sludge from the tanks. This had, of course, the effect of reducing the cost of sea disposal per ton.

DUBLIN.

233. At Dublin the whole of the sludge produced by the precipitation of the sewage with lime is taken to sea in the "s.s. Shamrock" and deposited in about 90 feet of water, some 2 miles N.E.E. of the Bailey Light on Howth. The following figures, which have been supplied to us by Mr. Spencer Harty, show the cost of disposal:—

THE FIGURES REFER TO THE YEAR ENDING OCTOBER 22ND, 1907.

Total quantity of sewage treated during the year. (Gallons).	Average daily quantity of sewage dealt with. (Gallons).	Total quantity of sludge produced. (Tons).	Percentage of water in sludge.	Total quantity of sludge sent to sea. (Tons).	Number of trips made by steamer.	Cost of sending sludge to sea, including all charges,* except the cost of filling the ship and interest and sinking fund on steamer. (Per ton of sludge.)	Cost of filling ship from sludge reservoir. (Per ton of sludge.)	Total cost of sending sludge to sea, including cost of filling ship, interest and sinking fund on steamer† and all other charges.* (Per ton of sludge.)
4,829,000,000	13,230,000	114,560	90 % (approx).	114,560	320	3·47d.‡	0·049d.	5·02d.

* In the case of Dublin no harbour dues are payable; the Corporation are the owners of Pigeon House Harbour.

† The average interest and sinking fund on the cost of the steamer (£11,139) is given as follows:—

Average sinking fund	£146
Average dividend	£362
Total	£508

The loan for the steamer is included in the loan for the entire main drainage works, and is repayable in 39 years.

‡ In this figure is included an item of £196 6s. 0d. for ropes, ironmongery, uniforms, lamps, clock, bedding, etc. The vessel is a new one, and this was her first equipment. The figure 3·47d. is somewhat high on this account.

SOUTHAMPTON.

234. At Southampton the sludge from the sedimentation tanks is pumped into a barge which is then towed by way of Spithead to a position 3 miles from land, when the sludge is discharged. The operation is carried out by contract, the Corporation paying 1s. 2d. per cube yard of sludge. The contractor supplies the barge and the tug. The capacity of the barge is 114 cube yards. The following figures relating to Southampton have been supplied by Mr. J. A. Crowther:—

THE FIGURES REFER TO THE YEAR ENDING MARCH, 1907.

Total quantity of sludge sent to sea.	Percentage of moisture in the sludge.	Number of journeys made by tug with barge.	Cost of disposal, excluding cost of filling barge and interest and sinking fund on pumping machinery.
16,896 cube yards or about 13,950 tons.*	about 90.	149	1s. 2d.† per cube yard or about 1s. 4·9d.* per ton.

* These are calculated figures; they are only approximate.
† This is the contract price.

235. SUMMARY OF FIGURES RELATING TO COST OF SEA DISPOSAL.

A. Place.	B. Year or years to which the figures refer.	C. Average annual quantity of sludge deposited at sea. (Tons).	D. Average percentage of water in sludge actually deposited.	E. Total cost of sea disposal, including cost of filling ship, interest and sinking fund, steamer dues and all other charges. (Per ton of sludge actually deposited.)	F. Total cost of sea disposal, including cost of filling ship, interest and sinking fund, steamer dues and all other charges. (Per ton of *dry solid matter*.)	G. Total cost of sea disposal, including cost of filling ship, interest and sinking fund, steamer dues and all charges; calculated as per ton of sludge containing 90 per cent. of water.	H. Remarks.
Glasgow	1906-7.	305,000	86·8	5·40d.	40·9d.	4·1d.*	Large quantity of thick sludge. Loan repayable in 60 years.
Salford	1902, 3, 4, 5, and 6.	136,000	79·0	9·45d.	45·0d.	4·5d.*	Heavy canal dues. Very thick sludge.
Dublin	1906-7.	114,560	90·0 ap.	5·02d.	50·2d.	5·0d.*	No harbour dues and short distance to dumping area.
London	1903, 4, 5, and 6.	2,534,000	92·0	4·55d.	56·9d.	5·6d.*	Very large quantity, but thin sludge.
Manchester	1903, 4, 5, and 7.	168,500	86·0 ap.	9·64d.	68·9d.	6·9d.*	Heavy canal dues.
Southampton	1906-7.	13,950	90·0 ap.	16·9d.	169·0d.	16·9d.	By contract.

* These are figures obtained by calculation, on the assumption—which is probably not quite correct—that it is as easy to deal with dense as with liquid sludge. There would probably be more wear and tear of machinery in the case of dense sludge, but on the other hand the same amount of solid matter in the form of liquid sludge might mean more steamer capacity. The figures in column G. must therefore be taken as giving only an approximate idea of comparative costs.

Pressing of Sludge.

236. The plan of pressing sludge is adopted at a large number of places. Strictly speaking, it is not a method of disposing of the sludge finally; but at by far the greater number of places where pressing is done, it has the effect of converting the sludge into a form in which it can either be sold to farmers for a return of something like 6d. per ton, or can be tipped or buried without serious expense. For this reason it may generally be considered an effective means of disposing of sludge.

Very briefly, the plan is as follows:—The sludge produced by the settlement of the sewage, with or without the addition of chemicals, is first run, or pushed by hand labour, from the settling tanks into a sludge well or tank. In this well it is allowed to settle for some little time, and, after the supernatant liquor has been drawn off, the thick sludge is mixed with from 0·5 to 1 per cent. of lime (or even more) in the form of milk of lime and then forced by means of compressed air into filter presses. In this way, on the average, something like 30 or 35 per cent. of the water in the wet sludge (which may be taken at approximately 90 per cent. on the average) is removed, leaving a moist but solid cake which may contain from 50 to 65 per cent. of water. The liquid pressed from the sludge is run back into the settling tanks for re-treatment. It is strongly alkaline, owing to the lime which has been added to the wet sludge. The pressed cake is scraped from the press-cloths into trucks and either sold to farmers, buried, or tipped. The cost of the process, excluding interest and sinking fund in respect of the pressing plant, may be put at from 2s. to 5s. per ton of pressed cake produced. As will be seen from the appended table, however, it varies largely at different places, depending mainly upon:—

(*a*) The amount of lime added to the sludge;
(*b*) The kind of sludge pressed;
(*c*) The size of the works at which the plan is adopted.

The variation in cost, dependent upon the kind of sludge to be pressed and the amount of lime to be added, is readily seen from the table.

As regards the variation in cost, dependent upon the kind of sludge to be pressed, it may be pointed out that the solid matter in septic tank sludge, especially in sludge from a tank which has been in use for a long time (say, a year) without cleaning, is generally in a very fine state of division. For this reason, a large quantity of lime has usually to be added to it, in order to prevent the press-cloths becoming clogged. At Hanley, it is true, only a very small amount of lime is used, but the septic tanks are cleaned out at short intervals (once every month), and there is a considerable quantity of "clay slip" in the sewage, which apparently helps the settlement and possibly delays the putrefaction of the sludge in the septic tanks. It is to be noted also that the milk of lime is added hot at that place.

At Nelson and at Burnley, where septic tank sludge is pressed, the quantities of lime added are respectively 9·6 per cent. and 15 per cent. of the pressed cake, and the cost of pressing, excluding interest and sinking fund, is 4s. 6·9d. and 4s. 3·4d., respectively. At Rochdale it was found necessary to add at least twice as much lime to the septic tank sludge as was required for the pressing of the chemical precipitation sludge, viz., 10 per cent. as against 5 per cent., calculated on the pressed cake. At York, so much lime had to be added to the septic tank sludge, in comparison with the amount required for the treatment of sludge from precipitation tanks, that the process was abandoned as being prohibitively costly.

We may refer also to the evidence given by Dr. James B. Wilkinson, who said that at Oldham they had found great difficulty in pressing the sludge from septic tanks.

In some cases, unusually large quantities of lime are added to precipitation sludge before pressing, but this is where manufacturing waste of a greasy nature finds its way into the sewers, or where, as in the case of Ealing, a specially hard cake is made, in order

In all cases, unless otherwise stated, the co eady to be pumped into the presses. The cost of sludging the sedimentation trucks below the presses.

A	B	C		L
Place.	Year to which the figures refer.	Population.	Kin	Remarks and Notes.
Hanley - - -	1907	66,000	Septic tritus	At Hanley the milk of lime is added hot to the sludge, as the latter is pumped into the sludge well. The mixture is then allowed to stand for several days before pressing. The septic tanks are

that it may subsequently be burnt. Generally speaking, there is no difficulty in pressing the sludge from precipitation or sedimentation tanks. It may be pointed out that the sludge from simple sedimentation requires, as a rule, the addition of more lime than the sludge derived from sedimentation after precipitation with chemicals; this is indicated in the table.

It may be useful to add here that success in pressing, whatever kind of sludge is being dealt with, depends very largely upon the intimate mixture of the milk of lime and the sludge. The dissolved lime has the effect of agglomerating the solids of the sludge, while the fine particles of undissolved lime, becoming interposed between the sludge particles, apparently provide small channels for the escape of the water. We may also mention that at York, Mr. Graham, the manager of the Sewage Works, found it useful to allow a small quantity of milk of lime to pass into the presses before the sludge, as the thin coating of solid lime thus formed on the press-cloths facilitated the subsequent pressing of the sludge and the removal of the cake.

Nuisance from Smell.

237. Speaking generally, properly pressed sludge when in the form of a solid cake does not give rise to serious nuisance from smell, and if exposed to the air in dry weather, it soon becomes entirely inoffensive. It has, however, a slight smell of fresh sewage, and if kept moist, *e.g.*, if it is exposed to the air during wet weather, it soon becomes putrid and gives rise to offensive odours. For this reason it should, if possible, be stored under cover, until it can be spread over land or dug into trenches or buried. At York, where a large quantity of pressed cake was tipped in the open, considerable nuisance is said to have arisen until Mr. Creer, the city engineer, adopted the plan of burying it, 5 or 6 feet thick, under a thin layer of soil and turf, when the nuisance entirely ceased. Incidentally, an uneven field is being levelled in this way.

Since there is almost always serious nuisance inside the press house, it is necessary that the house should be properly ventilated. It should also be situated as far as possible from any habitation, if complaint of nuisance is to be avoided.

Disposal of the Pressed Cake.

238. Pressed sludge can usually be disposed of to neighbouring farmers at about 6d. per ton. This, however, depends to a considerable extent upon the district in which the sewage works are situated. In some cases, *e.g.*, at Bury, Ealing (Northern Works), Wolverhampton, and Richmond, where the works are situated in densely populated districts, or are far removed from a railway, or in the case of a large town where the amount of sludge is greater than the neighbouring farmers require, the pressed cake has to be given away, or a small fee has to be paid for its removal.

The form of the pressed cake also affects its saleability; *e.g.*, at Burnley, where the Corporation break up the pressed cake immediately after pressing, a ready market is now obtained.

Composition of Pressed Cake.

239. The following figures of analysis give the chief mineral constituents and the nitrogen in the pressed cake from Chorley (Lancashire) and Dorking (Surrey), after complete drying at 110° C. These may be taken as more or less typical for domestic sewage, but there is more than the average quantity of lime in the Dorking pressed cake. The Chorley sludge is produced by the addition of about 9 grains per gallon of alumino-ferric to a sewage which is almost entirely domestic in character and of about average strength. The Chorley drainage area is sewered on the combined system. The Dorking sludge is obtained by the addition of about 5 grains per gallon of lime to a sewage of rather over average strength, and which, except for a small quantity of

brewery waste, is also almost entirely domestic in character. Dorking is sewered on the partially separate system.

	Chorley pressed cake after drying at 110° C. Sample drawn in April, 1905.	Dorking pressed cake after drying at 110° C. Sample drawn in April, 1905.
Grit, etc. (*i.e.*, matter insoluble in hydrochloric acid, after ignition)	25·30	6·84
Oxides of iron and alumina *	9·37	3·46
Lime †	10·32	23·16
Phosphoric acid (P_2O_5) ‡	0·98	0·66
Equivalent to tribasic phosphate of lime	2·14	1·44
Nitrogen (total) ‡	1·28	0·89
Nitrogen evolved on boiling the sludge for two hours with dilute (0·5 per cent.) potash solution	0·13 (May 21st.)	0·03 (May 20th.)

At Chorley the cake is sold for about 10d. to 1s. per ton, but at Dorking it is given away.

The calculated value of those two sludges in the form of pressed cake (50 per cent. moisture), as judged by their manurial constituents alone, is about 6s. to 7s. per ton, but, as experience shows, the market value is less.

Cost of Pressing Sludge.

240. In the majority of the cases cited in the table it has been impossible to ascertain the actual percentage of water in the wet sludge dealt with and in the pressed cake produced. We think, however, that it may be taken broadly that wet sludge contains on the average from 90 to 95 per cent. of water, and pressed cake about 55 per cent. of water. Upon this basis, and dividing our examples into two groups, we estimate the cost of pressing sludge as follows:—

Group I.

In this group we include towns having a population of about 30,000 and upwards, where the preliminary treatment consists either in chemical precipitation followed by sedimentation or in simple sedimentation, and where the sewage does not contain manufacturing waste of a kind likely to necessitate the addition of an unusual quantity of lime to the sludge before pressing.

If the sludge derived from precipitation or sedimentation tanks in these circumstances were to be pressed, it would require the addition of about 2 to 4 per cent. of lime, calculated on the pressed cake produced; and the cost of pressing, including lime, fuel, labour, press cloths, renewals and repairs, but excluding interest and sinking fund, would amount to from 2s. to 2s. 6d. per ton of pressed cake (55 per cent. water). This would be equivalent to from 5·3d. to 6·6d. per ton of wet sludge, containing 90 per cent. of water.

The interest and sinking fund charges, as given in the table, vary from 4½d. to 1s. 1d. per ton of pressed cake produced, or an average of 9d. per ton of pressed cake. This would be equivalent to 2d. per ton of wet sludge containing 90 per cent. of water. On this basis the *total* cost of pressing, including lime, fuel, labour, press-cloths, renewals and repairs, and also interest and sinking fund, would amount to from 2s. 9d. to 3s. 3d. per ton of pressed cake produced (55 per cent. water), or from 7·3d. to 8·66d. per ton of wet sludge, containing 90 per cent. of water.

Assuming that the pressed cake could be disposed of to farmers without further cost at a price of 6d. per ton, the total cost of sludge disposal at such places would be approximately from 6d. to 7·3d. per ton of wet sludge, including interest and sinking fund charges.

* These oxides will contain the phosphoric acid and possibly a very little of the lime.

† The lime was only precipitated once; it will contain traces of magnesia.

‡ The figures for phosphoric acid and for total nitrogen are the mean of two closely agreeing estimations.

Group II.

In this group we include towns having a population under 30,000 and also places where 5 to 20 per cent. of lime (calculated on the pressed cake) has to be added to the sludge before pressing, either because the sewage contains much grease, or because septic tank sludge has to be dealt with.

At such places the cost of pressing, including lime, fuel, labour, press-cloths, renewals and repairs, but excluding interest and sinking fund, would probably vary from 3s. to 5s. per ton of pressed cake (55 per cent. water), or from 8d. to 1s. 1½d. per ton of wet sludge containing 90 per cent. of water.

The cost of pressing, including lime, fuel, labour, press-cloths, renewals and repairs, and also interest and sinking fund, at such places would be from 3s. 9d. to 5s. 9d. per ton of pressed cake (55 per cent. water), or from 10d. to 1s. 3½d. per ton of wet sludge containing 90 per cent. of water.

Assuming that the pressed cake could be disposed of without further cost at a price of about 6d. per ton, the net cost of sludge disposal at these places would be from 8·66d. to 1s. 2d. per ton of wet sludge, including loan charges.

From these figures it will be seen that, in the case of large towns, the cost of the disposal of sludge by pressing is about the same as the cost of depositing it at sea. For small towns or for places where septic tank sludge has to be disposed of, the cost is considerably greater. In all cases the cost turns very much upon whether there is a ready sale for the pressed cake, and this is dependent upon having facilities for carting or sending by rail to outlying districts. The pressed cake is worth much more than 6d. per ton, judged by its manurial constituents; the reason that it fetches such a low price is the relatively high cost of carriage upon a mixture containing of necessity a large proportion of water, grit, and carbonaceous matter.

Shallow Burial of Sludge in the Ground.

241. This plan of sludge disposal consists in mixing the wet sludge from precipitation, settlement, or septic tanks as rapidly and as thoroughly as possible with surface soil. It is usually carried out in the following manner: Small V-shaped trenches, about 2 feet wide at the top and (excluding banking above the surface of the soil) about 1 foot deep, of sufficient capacity to hold the quantity of wet sludge to be disposed of, are cut, if possible, a month or even two months before they are likely to be required, in order to dry and disintegrate the soil. The wet sludge is then run into the trenches and immediately covered over by shovelling in the earth of the banks. The area thus treated is allowed to remain untouched until it is fairly dry, after which it is ploughed and either set aside for cropping or used again for more sludge.

This plan is not widely followed at present, excepting at sewage farms, but it has lately been worked with considerable success by Mr. J. D. Watson, at Birmingham, Mr. C. G. Mason, at Guildford, and Dr. G. J. Fowler, at Withington, in conjunction with artificial filters. By this plan the sludge is cheaply and effectively disposed of, but in wet weather the trenches, both empty and full, require a long time to dry, and, where an offensive sludge has to be dealt with, local nuisance from smell may easily arise.

At Birmingham, where the septic tank sludge has very little smell, little or no nuisance arises, notwithstanding the enormous quantities dealt with; but at Guildford, owing to the presence of brewery waste in the sewage, there is considerable smell from the trenches. We may point out, however, that strongly smelling sludge can be to a large extent deodorised by the addition of a moderate quantity of lime, and for this reason, though we have no practical experience of the plan, we think that at those places where an offensive sludge had to be dealt with, serious nuisance could be avoided without great cost. At small or medium-sized works, where septic tanks are in use and are cleaned out, say, once every six months, it appears to us that it would be quite practicable to add sufficient lime to the sludge to deodorise it, *before conducting it to the trenches.* This method of disposal would be peculiarly suitable for the treatment of the sludge which is removed from septic tanks at fairly long intervals of time, for in that case a period of dry weather could be selected for the trenching operations.

Area of Land Required.

242. With regard to the kind of land and the area required for the annual disposal of 1,000 tons of wet sludge (90 to 95 per cent. of water), we may quote some particulars which have been given to us.

Mr. J. D. Watson writes (April, 1907) :—

"I cannot differentiate between one kind of land and another, since we have in "the valley of the Tame a great variety of soil. . . . Even in one field we have "occasionally considerable areas of very close marl and equally great areas of "fairly porous gravelly marl. The figure which I give, therefore, is one which "embraces various kinds of soil, but as it is the result of an average taken over "three years, I think it may be assumed to be fairly accurate as representing "*medium quality* of land."

The following table shows the amount of wet sludge dealt with at Birmingham and the area of land used in the form of trenches :—

Year.	Tons of wet sludge dealt with by trenching.	Area of trenches in square yards.	Area of trenches in square yards per 1,000 tons of wet sludge.
1903–4	208,350	265,870	1,276
1904–5	239,203	248,132	1,038
1905–6	109,255	74,167	680
1906–7	104,780	82,747	788

"Climatic conditions have also a considerable bearing upon this question. "In dry weather more sludge can be got rid of on the same area of land than "in wet weather. Methods of working have also a good deal to do with the "results obtained. For instance, where possible it is advisable to cut the trenches "a month or two in advance of their being required, in order to dry the land as "thoroughly as possible. . . .

"Speaking generally, I should say that a quarter of an acre of medium quality "land, worked under usual conditions in this country, is amply sufficient to deal "with 1,000 tons of wet sludge (90 per cent. to 95 per cent. water) per annum."

Mr. C. G. Mason writes (April, 1907) :—

"During 1906, 18,720 tons of liquid sludge were applied to nine acres of "land at Guildford. In the winter months one acre is sufficient to deal with "approximately 2,000 tons, and in the summer months nearly twice that "quantity can be dealt with on the same area of land. The land available for "sludge purposes at Guildford may be described as excellent, consisting as it does "of a light sandy loam, overlying a bed of sand to the depth of 6 feet, with "the water level from 3 to 6 feet below the surface, according to season."

Mr. Mason says that he has not had any experience in dealing with liquid sludge upon unsuitable land, but from general experience he estimates the areas required annually for the disposal of 1,000 tons of wet sludge to be as follows :—

Good land	½ acre.
Medium land	1 „
Bad land	2 acres.

"The plan of trenching has certainly been very successful at Guildford, and has "saved the Corporation a large sum yearly from its inception, but I should not care "to make an experiment with wet stiff clay land, an absorbent sub-soil being to "my way of thinking an essential necessity for trenching the precipitated matter "from sewage tanks."

As regards the Withington Sewage Works of the Manchester City Corporation, where the same plan of sludge disposal has been adopted, Dr. G. J. Fowler writes (January, 1908) as follows :—

"The soil at Withington may be described as a sandy loam with a water-logged "subsoil. I should certainly class it as 'medium' soil. For the annual disposal "of 1,000 tons of wet sludge I am of opinion that two acres of such soil should "be provided, though the more soil you have at your disposal the better. Some-

"thing will here depend upon the character of the sludge. The Withington sludge "itself contains a good proportion of sand (77 per cent. SiO_2; 1·76 per cent. "Al_2O_3); a sludge containing a larger percentage of clay, *e.g.*, Davyhulme sludge "(44·3 per cent. SiO_2; 20·85 per cent. Al_2O_3), might require a greater area of "such land.

"Even with the best sandy soil I should recommend, if possible, one acre per "1,000 tons of wet sludge, if it is to be dealt with to the best advantage.

"I am very doubtful whether it is possible to dispose of sludge on clay land, "without some provision of shallow lagoons artificially drained, *e.g.*, by banks of "clinker at frequent intervals.

"Some addition of lime is advisable in all cases where this has not been added "in the course of chemical treatment, either to neutralise the acid produced by "the decomposition of fats or the sulphuric acid produced by the oxidation of "sulphides in sludge from septic tanks."

Allowing ample margin for contingencies, cropping and bad weather, we should from these figures recommend the provision of the following areas of land for the yearly disposal of 1,000 tons of wet sludge (90 to 95 per cent. water) :—

Good or fairly good soil	1 acre.
Medium soil	2 acres.
Stiff clay soil,—at least	3 „

Care would have to be taken, as Mr. Watson suggests, to prepare the trenches beforehand, so that the soil might be as dry as possible, and also to remove the sludge from septic tanks in the dry season of the year.

It would be important, moreover, in calculating the amount of sludge likely to be produced at a given place, to include storm water sludge, especially if * stand-by tanks were used for the treatment of the storm water. Tanks of this kind would have to be frequently sludged, and consequently special areas of trenches would be required.

At those places where continuous filters of coarse material were adopted, it would also be necessary to provide for the disposal of the sludge settled out from the effluent.

It must not be forgotten that the disposal of sludge upon land is temporarily interfered with by snow and frost.

Cost.

243. As regards the cost of sludge disposal by burial in the ground, the following particulars relating to Birmingham, Guildford, and Withington have been supplied to us. In all three cases the cost is taken as beginning after the sludge has left the sedimentation tank (*i.e.*, the actual sludging of a tank is not included), and as ending when the trenches are filled in with earth.

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TOTAL COST OF CONVEYING SLUDGE TO THE LAND AND DEPOSITING IT IN TRENCHES CUT FOR THE PURPOSE.

	Year 1905.	Year 1906.	First 11 months of 1907.
	£. s. d.	£. s. d.	£ s. d.
Working expenses of steam plant and attendance :			
Engineers and Stokers	65 16 2	70 4 6	76 3 9
Oil, waste, valves, etc.	100 0 0	106 0 0	92 0 0
Coal	83 16 3	89 8 9	77 12 6
Digging trenches, covering sludge, filling in trenches, etc.	719 18 2	644 6 9	516 9 0
Total working cost	969 10 7	910 0 0	762 5 3
Interest on Capital Outlay at 5 per cent., viz., Pump House, Sludge Main, etc.	220 0 0	213 0 0	130 0 0
Rent of land	23 0 0	22 0 0	13 0 0
Total cost, including interest on capital	£1,212 10 7	£1,145 0 0	£905 5 3
Total amount of wet sludge dealt with (90 per cent. to 95 per cent. water)	Tons. 84,890	Tons. 61,996	Tons. 48,872

* *See* section dealing with treatment of Storm Water Sewage, page 204.

At Birmingham the total cost of this method of sludge disposal, including labour, pumping, fuel, interest and sinking fund and rent of land, was therefore approximately 4·0d. per ton of wet sludge containing from 90 to 95 per cent. of water.

Guildford.

Total cost of conveying the sludge to the land and depositing it in trenches cut for the purpose. The figures refer to the year 1905–6.

	£	s.	d.
Two men employed continuously for regulating and covering in the sludge	101	8	0
One man 3 days per week attending to steam boiler and sludge pump	31	4	0
Firewood for boiler (4 loads @ £1)	4	0	0
Disinfectants	20	0	0
30 tons of fuel for generating steam for pumping sludge	36	0	0
Renewals and sundries	2	8	0
Annual working cost	195	0	0
Add interest and sinking fund for 17 acres of land	252	15	3
	447	15	3

The total quantity of liquid sludge dealt with during the year was 18,720 tons. The cost at Guildford was thus 5·2*d.* per ton of wet sludge, containing from 90 to 95 per cent. of water.

Withington.

The following statement relative to the cost of trenching at Withington has been given to us by Dr. Fowler (January, 1908):—

"The cost of excavating a measured trench, capable of holding 1 cubic yard of "sludge, has been found by the manager of the Withington Works, Mr. C. H. Ball, "to be 1·3d. This low cost is due to the fact that the soil thrown up on either side "of the excavation practically doubles the holding capacity.

"Taking the average cost for the whole year per ton of wet sludge for cutting "and filling trenches, it comes to 2·4d. and the total cost for sludge disposal works "out at about 5·5d. This is exclusive of the rent of land, which would bring the "total up to about 7·0d., if only so much land is charged for as is absolutely "necessary."

The population draining to the Withington Works is approximately 59,000. The total annual production of wet sludge is something like 14,000 tons.

Lagooning or Air Drying.

244. A lagoon in connection with sludge disposal may be described as an earth tank, from 1 to 6 feet deep, constructed by excavation and banking, or banking alone, with a bottom layer composed of clinker or some such material, in which are laid one or two drains. Occasionally the whole enclosure is constructed of clinker, the banking being made with an easy slope, formed naturally by the fall of the clinker.

Lagooning consists simply in filling such a tank with wet sludge, by gravitation or by pumping, and allowing it to remain there until, partly by evaporation and partly by draining, the sludge becomes dry enough to be removed by spade. When the sludge reaches this state, it is usually wheeled out of the lagoon and dumped on waste land.

There is in our opinion very little to be said for the lagooning of sludge. Once in the lagoon the sludge may take from 2 to 6 months to dry, according to the weather, and during the greater part of this time smell may be said to arise from it. Further, when the sludge is dry enough to be removed, it has still to be disposed of, and being usually moist and closely bound together, it is not readily taken by farmers. The time required by the sludge to dry, however, depends to a great extent upon the depth and the draining of the lagoon. At Darwen, where a large quantity of lime is added to the sludge, and where this mixture is given further settlement in special tanks, the lagoons are only filled to a depth of about 1 foot. As the result of this whole procedure, the

sludge is usually just spadeable in 2 or 3 days—a very short space of time. It is then given away to farmers, the Corporation filling the carts free of charge. At Accrington the lagooned sludge, when dry enough to be spadeable (this takes from 2 to 3 months in dry weather, while in wet weather it may require about 6 months), is sent up the steep side of the quarry in which the works are situated, by means of a truckway, and deposited in canal barges, to be taken to the more purely agricultural districts of West Lancashire. The barge owners pay, on the average, about £2 10s. per barge load of 45 tons. The barges are loaded by the Joint Sewerage Board, the average cost of filling a boat from the works being about 25s.

At Leeds lagooned sludge has gradually accumulated during the past ten years, only a few thousand tons per annum having been disposed of to farmers. We are, however, informed by Mr. G. A. Hart that, as the result of practical advertisement, arrangements have now been made for reducing those accumulations, the sludge being sent by rail or canal to the agricultural districts around Leeds. The loading costs the Corporation 1s. 2d. per ton of sludge (60 per cent. moisture), the farmers who receive it paying the carriage, which amounts to about 1s. 6d. per ton. During the past 7 months 6,000 tons have been disposed of in this way.

It is possible to lessen very greatly the smell from a sludge lagoon by covering the surface of the sludge with soil. This can only be done, however, after the sludge has been in the lagoon sufficiently long to allow of its surface drying into a cake. The plan, moreover, is one which might result in serious danger to workmen or children, especially if the lagoons were deep.

Covering Land with Sludge.

245. This plan consists in simply flooding an area of flat land, which has previously been ploughed, with wet sludge to a depth of 3 or 4 inches. In a few days the liquid portion of the sludge drains away, leaving a layer of sludge which cracks and curls up as it dries. The only examples of the method that we are acquainted with are at Birmingham and Bolton. At Birmingham Mr. J. D. Watson has carried out the plan with success. In his evidence he stated:—

"If the sludge has been subjected to digestion in septic tanks for a sufficiently "long period, it loses its characteristic pungent and offensive odour. It may either "be pumped into trenches or even put on the surface of land and exposed to the "air until dry, without giving rise to smell; when thus treated it rapidly settles "down in bulk, and as it dries the surface cracks up. In the course of a few "months it assumes the appearance of a rich black soil." Watson, 25,034

At Bolton a somewhat similar plan is adopted for the disposal of part of the precipitation sludge from the Hacken sewage works. In this case the land is first ploughed and the sludge is allowed to spread over it, the flow being equalised as much as possible by means of cross grips cut through the furrows. Another plan which is adopted, when possible, is to drill the soil (as for mangolds) and then run the sludge along the bottom of the drills. When the sludge is dry, it is covered over by ploughing or splitting the drills and a crop is taken.

The land treated in this way at Bolton is either sandy clay loam or sandy gravel.

Mr. Ashton, the Manager of the Bolton works, estimates the area of land required for the annual disposal of 1,000 tons of sludge containing 90 per cent. of water as follows:—

(1) Good, or fairly good soil - - - - - - - ¾ of an acre.
(2) Medium soil such as sandy loam - - - - - - 1 acre.
(3) Heavy soil - - - - - - - - - 2 acres.

The plan would be quite unsuited for strongly smelling sludge, unless the land used for the purpose were far removed from houses or public roads, or unless the sludge were deodorised in the first instance by the addition of lime or some other suitable substance.

Sludges which give rise to little or no smell are very exceptional. The Birmingham septic tank sludge is comparatively free from smell, but the majority of septic tank sludges from domestic sewage, even when they have remained for a long period of time in the tank, are very far from odourless. We have made no observations at Bolton, but the sewage there contains much manufacturing waste, which may possibly keep down smell.

Cost.

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246. Two sets of figures have been given to us by Mr. Watson, viz., the cost of disposing of the sludge from the Saltley septic tanks, and the cost of disposing of the sludge from the Dortmund or silt tanks at Minworth, these latter being used for the further settlement of the septic tank liquor before filtration. In the first case the sludge is pumped, but in the second no pumping is necessary. In both cases it is septic tank sludge that is dealt with.

TOTAL COST OF CONVEYING THE SEPTIC TANK SLUDGE FROM SALTLEY TO THE LAND AND DEPOSITING IT.

Working expenses of steam plant and attendance.	Year 1905.	Year 1906.	First 11 Months of 1907.
	£ s. d.	£ s. d.	£ s. d.
Engineers and Stokers	33 13 9	26 10 10	48 11 8
Oil, waste, valves, etc.	44 0 0	34 13 4	58 13 4
Coal	37 2 6	29 5 0	49 10 0
Distribution of sludge over land	45 13 3	50 7 4	42 12 1
Total working cost	160 9 6	140 16 6	199 7 1
Interest at 5% on Capital outlay—viz., Pump House, Sludge Main, etc.	130 0 0	137 0 0	191 0 0
Rent of land	13 0 0	16 0 0	19 0 0
Total cost, including Interest on Capital	£303 9 6	£293 16 6	£409 7 1
Total amount of wet sludge dealt with (90% to 95% water)	50,365 tons	42,278 tons	71,265 tons

The cost of this method of disposal was thus **1·47**d. per ton of wet sludge, containing from 90 to 95 per cent. of water.

TOTAL COST OF CONVEYING SEPTIC SLUDGE FROM MINWORTH AND DEPOSITING IT ON THE LAND.

	Year 1905.	Year 1906.	First 11 months of 1907.
	£ s. d.	£ s. d.	£ s. d.
Attendance to Silt Tanks	6 10 0	14 5 3	18 2 1
Distribution and digging into land	16 15 0	37 14 9	44 1 5
Total working cost	23 5 0	52 0 0	62 3 6
Interest on Capital Outlay, viz., Silt Main	57 10 0	57 10 0	57 10 0
Rent of Land	9 0 0	20 0 0	13 5 10
Total cost, including Interest on Capital	£89 15 0	£129 10 0	£132 19 4
Total amount of wet sludge dealt with (90% water)	6,226 tons.	21,605 tons.	36,299 tons.

The cost of disposal in this case was therefore **1·32**d. per ton of wet sludge containing 90 per cent.* of water.

BOLTON.

247. In the case of Bolton the total cost of the plan for the year ending November 30th, 1907, when 25,000 tons of sludge containing 90 per cent. of water were dealt with on 25 acres, was approximately 5·04d. per ton.

* The above figure of 90 per cent. water in the sludge was in this case actually determined.

It should be noted, however, that the sludge gravitates to the land from the precipitation works at Hacken—a distance of some miles—through a conduit which is used chiefly for the conveyance of tank liquor to the land for filtration. No portion of the interest and sinking fund charges on this conduit are included in the above cost for sludge disposal.

Burning of Sludge.

248. There have been many attempts to dispose of sewage sludge by burning it either alone or mixed with house refuse, coal, oil, or resin. Most of these have failed, owing either to the heavy cost of drying the sludge before burning, or to the fact that the attempt was made on wet sludge containing something like 90 per cent. of water. It is practicable, however, to burn pressed cake. At Ealing (Southern Works) Mr. Charles Jones has for some years disposed of pressed sludge (containing about 60 per cent. of water) in this way. At those works the pressed cake is dropped from the presses into trucks, which are then conveyed by a hydraulic lift to the destructor furnaces. There it is mixed with dry house refuse, in the proportion of about 1½ or 2 parts of dry refuse to 1 of pressed cake, and burnt. The steam generated is utilised for lime mixing, for sludge-pressing and the manufacture of artificial paving slabs, and for pumping a portion of the sewage. We have not been able to ascertain the cost of the process, but about 2,500 to 3,000 tons of pressed cake have been disposed of per annum in this way during the years 1905, 1906, and 1907.

249. Reference may also be made to the evidence given by Mr. K. F. Campbell of Huddersfield in regard to an *experimental* plant. At that place a portion of the sludge obtained by means of chemical precipitation is pressed and, having been tipped into feeding bins at the back of the furnaces, is there mixed with 20 per cent. of coke breeze and fed by hand into the furnaces. The burning plant consists of a two-cell Horsfall destructor, each cell having a grate area of 30 square feet, with a drying hearth at the back; the cells are placed side by side and each is fitted with a patent Silent Steam Blower. The furnaces are so arranged that all the fumes given off by the pressed cake, in drying, have to pass over the hottest part of the fire before they escape to the chimney. Campbell 802.

Mr. Campbell's original intention was to burn the pressed sludge mixed with an equal quantity of town refuse, but owing to the difficulty in getting the refuse to the sewage works, this was abandoned and coke breeze was substituted. Occasionally a little engine slack has been used, mixed with the coke breeze, but this is not a regular occurrence. During the year 1907 a trial has been made with gas-works clinker containing a fair proportion of coke and combustible matter. The following particulars relating to the years 1901–6, inclusive, have been kindly given to us by Mr. Campbell:—

Year ending:—	Sludge Cake burnt in destructors.	Coke Breeze used.	Coal used.	Gasworks clinker used.
	TONS. CWT.	TONS. CWT.	TONS. CWT.	TONS CWT.
March, 1901	5,421 14	911 1	121 0	101 16
" 1902	34 8	7 10	—	—
" 1903	136 0	27 9	—	—
" 1904	220 14	42 11	—	—
" 1905	61 3	7 8	2 17	—
" 1906	74 9	12 9	—	—
Total	5,948 8	1,008 8	123 17	101 16

The proportion of fuel added to the pressed cake was thus about 1 to 5.

The clinker obtained from the burnt sludge is rather too friable for use in sewage filters, but Mr. Campbell states that when it is ground up and mixed with cement or lime it forms an excellent mortar, of which much has been used in the present re-construction of the works.

Cost.

The cost of pressing and burning varies with the price of the materials (lime, coke breeze, etc.). The following are the average costs for each :—

PRESSING.

Cost per ton of Pressed Cake Produced.

	s.	d.
Labour	1	5·3
Lime (13s. 3d. per ton)	–	9·3
Press Cloths	–	3·7
Total	2s.	6·3d.

BURNING.

Cost per ton of Sludge Cake Burnt.

	s.	d.
Coke Breeze (7s. 6d. per ton)	1	6·4
Stokers	–	7·2
Mixers	–	5·3
Total	2s.	6·9d.
Total cost of pressing and burning (per ton)	5s.	1·2d.

These figures do not include cost of power for pressing, on the one hand, but, on the other, no allowance has been made for fuel value or for clinker produced.

It will be seen that the above process, as carried out on a large experimental scale at Huddersfield, is costly, but probably the whole of the final product can be utilised and the sludge is entirely got rid of.

Extraction of Valuable Substances from Sewage Sludge.

250. The chief example of the extraction of a valuable substance from sewage sludge is afforded by Bradford. As is well known, the sewage there contains a considerable quantity of wool-scouring liquor and is consequently of a very greasy nature. For some years experiments having for their object the extraction of the grease have been in progress, and Mr. J. Garfield, the City Engineer, has now been so far successful that the return from the sale of the products more than meets the working expenses of the tank treatment of the sewage,* leaving out of account the charges in respect of principal and interest on loans. The dry weather flow of sewage is approximately 13,000,000 gallons per day, about half being trade waste. Of the trade waste 20 per cent. is wool-scouring liquor, and of this about 90 per cent. is treated by manufacturers for the recovery of grease before being discharged from the premises. The remaining 80 per cent. of trade waste comes from dyers, printers, chemical manufacturers, tar distillers, cloth manufacturers, waste pullers and scourers, yarn finishers, cloth washers, carbonizers, silk manufacturers, tanners, oil distillers, paper manufacturers, size manufacturers, brewers and galvanizers. In all, about 274 traders discharge their waste liquor into the sewers.

The process of treating the sewage at the works is as follows: The sewage is passed through detritus tanks, from which about 10 cubic yards of detritus are removed per day. It is then screened and sulphuric acid is added in such quantity that there is an excess equal to 10 parts of acid (H_2SO_4) per 100 000. The acid sewage is subsequently

* The treatment of the sewage at Bradford does not go beyond precipitation.

passed through settling tanks, used in series, the tank liquor being discharged into the Bradford Beck in a slightly acid condition. The following figures give the average chemical composition of the sewage and the tank liquor :—

	Parts per 100,000.	
	Crude sewage.	Tank liquor.
Suspended matter	84·0	16·0
Solids in solution	181·0	224·0
"Oxygen absorbed" in 4 hours	17·90	11·18
Free ammonia	3·00	1·87
Albuminoid ammonia	2·45	1·80

The sludge is removed from the settling tank into cast iron vats, where a further quantity of sulphuric acid is added and the temperature of the sludge is raised by means of exhaust steam from the boilers to about 100°C. It is then run into steel rams and forced by means of compressed air into the filter presses. The filter presses are heated by steam, and the process of pressing is continued from 12 to 24 hours, hot sludge and steam being alternately admitted to the press. The pressed liquor, which consists of water and fat, is run into special vessels for the separation of the fat, after which the fat is boiled with acid and black oxide of manganese, in order to bring it into a marketable condition.

The amount of wet sludge produced in a year is about 100,000 tons. It contains about 80·15 per cent. of water and 7·43 per cent. of grease, which is equivalent to 37·7 per cent. of grease on the dry solid matter.

The amount of pressed cake produced during the year is about 20,000 tons. This contains about 27 per cent. of water. Part of the pressed cake is used for fuel and is burnt in specially constructed brick furnaces; the fuel value is about 1s. 6d. per ton. Part is sold to farmers at 3s. 6d. per ton on rail at the works. Another portion is disintegrated and sold as manure at 5s. 6d. per ton, whilst 6s. 3d. per ton is obtained for the driest portion of the disintegrated pressed cake.

For the six months ending September 30th, 1907, the total expenditure on the sewage works, exclusive of principal and interest on loans, amounted to £9,960 0s. 3d. and the receipts from the sale of grease, etc., to £11,726 15s.

The following table, which has been given to us by Mr. Garfield, shows the figures in detail. The expenditure includes the salaries of the chemical and clerical staff, and the whole of the costs in connection with the Sewage Disposal Works, except the Chief Engineer's salary, and interest and sinking fund on loans.

EXPENDITURE.	£	s.	d.	RECEIPTS.	£	s.	d.
To Sulphuric Acid, Fuel and Stores	7,250	3	4	By Grease, Manure, etc.	11,726	15	–
To Salaries and Wages	1,907	12	–½				
To Gas	161	11	3				
To Water	90	19	10				
To Insurance and Sundries	122	13	9½				
To Rent, Rates and Taxes	427	–	–				
To Balance	1,766	14	9				
£.	11,726	15	–	£.	11,726	15	–

251. We may also refer to a process of sludge distillation (Watson and Butterfield's Patent Sludge Distilling Process), which was brought to our notice by Mr. George Watson of

the Horsfall Destructor Co., Ltd. The object of this process, an experimental installation of which was inspected by one of our officers on July 6th, 1907, is to recover the nitrogen from the sludge in the form of ammonia, and to utilise at the same time the carbonaceous matter for the purpose of generating heat. The following description of the process has been supplied by Mr. George Watson. It must, of course, be understood that we are not responsible for the claims advanced by Mr. Watson, in regard to the process. We can express no opinion in regard to them.

"The treatment of the sludge as taken from the precipitation tanks involves, on this principle, three "separate processes. Firstly, the removal of a portion of the water by mechanical means; secondly, "the removal of a further portion of the water by drying; and thirdly, the destructive distillation of the "partially dried sludge."

(1) *Pressing.*

"The sludge when taken from the precipitation tanks contains about 90 per cent. of water. The "best method at present in use for getting rid of some of this water is filter-pressing. By this means the "proportion of water in the sludge may be reduced to 50 or 60 per cent.'

"Sludge containing 90 per cent. of water, when pressed until it contains 60 per cent., is reduced to "one-fourth of its original bulk; if pressed until it contains 50 per cent. of water, it is reduced to one-"fifth of its original bulk. The cost of filter-pressing is in one instance as low as 1s. 10d. per ton of "pressed cake, but the average cost at the present time may be put at from 2s. 3d. to 2s. 6d. per ton "of pressed cake containing from 50 to 60 per cent. of water."

(2) *Drying.*

"After the sludge has been filter-pressed, it is necessary to dry it until it contains only 20 to 25 per "cent. of water, before putting it into the retort for distillation. Wherever a sufficiently large space "of ground is available and only a comparatively small quantity of sludge has to be treated, the drying "may be most economically effected by exposing sheds. Where considerations of capital are not deterrent "or where space is limited, the sludge may be dried by passing it through mechanically driven rotary "cylindrical driers, heated by the hot waste gases of combustion, which leave the flues round the distilling "retort after having heated the retort.

"The sludge as it leaves the filter-presses can be readily transported to the driers on band-conveyors. "Filter-pressed sludge containing, say, 60 per cent. of water, when dried until it contains 20 per cent. "of water, is reduced approximately to half its weight and bulk.

"The sludge is now in the form of sufficiently dried cakes to be easily transportable mechanically "by conveyors or elevators to the retort, and suitable for the treatment by destructive distillation at a "high temperature.

"The gases from the interior of the cylindrical drier, before reaching the chimney, may be passed "through a scrubber which recovers any ammonia given off by the sludge during drying operations, "thus effectually preventing any smell which may arise from this source.

"The cost of drying is estimated at 1s. 6d. per ton of dried sludge (containing 20 per cent. of water), "which is equivalent to a cost of 9d. per ton of filter-pressed sludge containing 60 per cent. of water."

(3) *Destructive Distillation.*

"The retort used for the distillation may be of firebrick, but is preferably made of cast iron, and is "oval in section, so as to enable the heat to penetrate readily through the material in the interior.

"The retort is set vertically and is slightly larger in section at the bottom than at the top, so as to "facilitate the downward movement of the sludge cake. The top of the retort is closed air-tight by a "cup and cone arrangement, through which the dried sludge cake is fed at regular intervals. The bottom "of the retort is similarly closed by a cone, which can be operated so as to let out the spent residue from "the distillation, as may be desired. The retort is placed in a brickwork setting and is heated by the "combustion of gas in a combustion chamber and in flues passing around and up its sides, preferably "in a spiral path.

"The volatile products arising from the distillation are taken off towards the top of the retort through "a pipe connected to the side, and the gases are pulled forward and outward by an exhauster which "maintains a pressure inside the retort slightly below the atmospheric pressure.

"After leaving the retort the volatile products of distillation are passed through a condenser and "subsequently through a scrubber, which extracts the moisture, oil, tar and ammonia. The inflammable "gas which now remains is passed into the combustion chamber of the retort and there burnt.

"The heat obtained from the combustion of this gas is sufficient to maintain the retort at the desired "temperature, but an auxiliary source of heat is provided by a gas producer or furnace which is used in "starting the operation.

"The lower part of the retort is maintained at a temperature of 1,500° to 1,800° F.

"Steam is blown into the retort, near the bottom, and in passing through the hot zone in the retort "it reacts on the carbonaceous material of the sludge, and in the presence of the lime, and at the high tem-"perature there existing, the nitrogen in the sludge is liberated and evolved as ammonia.

"The products obtained from the distillation are: (1) Oil; (2) ammonia; (3) combustible gas; "and (4) mineral residue."

(1) *Oil.*

"The oil is run off from the top of the ammoniacal liquor coming from the condenser, by means of an "oil separating tank. The oil thus obtained has not yet been thoroughly examined, but it probably has "a value far higher than that of fuel oil, although this is not necessary for the economical success of the "process.

"The yield of oil depends on the method of distillation, being much greater if a comparatively cool "zone is maintained at the top of the retort. The yield of oil from the sewage of different localities also "varies greatly."

(2) *Ammonia.*

"The ammoniacal liquor from the condenser and scrubbers is treated with sulphuric acid in the ordinary "way and is converted into ammonium sulphate.

"The yield of ammonia varies to some extent with the locality from which the sewage is derived. The "economical disposal of sewage sludge in this way depends on the recovery of the ammonia from the "sludge in sufficient quantity to cover the cost of treatment."

(3) *Gas.*

"The gas is burnt around the retort and provides the heat necessary for the distillation."

(4) *Residue.*

"The spent residue from the retort is freed entirely from any trace of organic matter by its treat-"ment in the retort, and is of a light friable nature and easily reduced to a fine powder. It contains "lime and some phosphates and is in a form very suitable for direct application to land, either alone "or enriched by the addition of concentrated manures. On the other hand it might possibly be used "as a precipitant for the sewage, along with a small proportion of fresh lime. By constantly using the "same material over again, the percentage of phosphate of lime in the material would be so increased "as to make it valuable as a manure. Where too much iron is not present, the residue can be used as "a cement of fair quality.

"The quantity of residue remaining after distillation is about 50 per cent. of the solid material present "in the sludge, or 40 per cent. of the sludge (containing 20 per cent. of water) as charged into the retort. "The percentage of residue varies in different localities according to the amount of surface water run "into the sewers. In some cases a large amount of mineral matter is thus swept into the sewage, which "increases the proportion of inorganic solids in the sludge."

The following figures show the amounts of the different products obtained by this process of distillation. In every case, to avoid confusion, the figures given are calculated per ton of *absolutely dry sludge*—that is, per ton of solid matter in the sludge.

Date.	Locality from which the sludge was obtained.	Oil.	Ammonium Sulphate.	Residue.
October, 1906 -	Bradford - - -	Not measured.	97·7 lbs.	42% (small sample only tested).
" " -	Bury - - -	30 gallons.	120 lbs.	47% do.
" " -	" - - -	37 "	124 lbs.	47% do.
" " -	Southall - - -	6·2 "	81·7 lbs.	47% do.
April, 1907 - -	Leeds - - -	24 "	103 lbs.	50% do.
October, 1907 -	" - - -	*Not measured.	109·2 lbs.	50% (one ton distilled in large retort).

* The retort was too hot at the top to yield oil.

Comparison of Cost of Different Methods of Disposal of Sludge.

252. The cost of disposing of sludge depends not merely upon the method adopted, but also, and to a large extent, upon the local circumstances of each place. This must be carefully borne in mind in considering the following table :—

Comparative Cost of the Various Methods of Sludge Disposal, as instanced by the Examples Given.

Method of sludge disposal.	Number of examples.	Maximum and minimum cost of the process, in pence, per ton of sludge containing 90 per cent of water, including interest and sinking fund and all other charges.*	Average cost of process, in pence, per ton of sludge containing 90 per cent of water, including interest and sinking fund and all other charges.
Covering land with sludge	3	Minimum 1·32d. Maximum 2·8d.	say, 2d.
Sea disposal	6	Minimum 4·1d. Maximum 6·9d.	say, 5d.
Trenching in soil	3	Minimum 4·0d. Maximum 7·0d.	say, 5d.
Pressing. Group I.	10	Minimum 4·8d. Maximum 7·3d.*	say, 6d.
Pressing. Group II.	11	Minimum 7·7d. Maximum 12·6d.*	say, 11·5d.
Pressing and burning	1 (experimental)	13·3d. (excluding interest and sinking fund.)	say, 18d.†

The cheapest examples of disposing of sludge come under the heading of "covering land with sludge." This is, of course, what would be expected, for little labour is necessary in connection with the plan. The success of the method depends upon having a sufficient area of good, or fairly good, soil in flat formation. On account of smell, the plan would, as a rule, only be suitable where the sewage works were far removed from houses and public roads.

The two cases of an actual profit arising out of the disposal of the sludge, viz., Kingston-on-Thames and Bradford (Yorkshire) are not included in the table.

In the table no credit has been given either for the manurial value of the sludge disposed of by covering land or trenching, or for the fuel value of the sludge and the production of clinker in the "burning" method.

With regard to the burning of sludge, if this process were so modified as to permit of the recovery of the nitrogen of the sludge, its cost would probably be much reduced.

* Owing to the great variations in the actual figures for interest and sinking fund, mainly because of the different dates at which the sewage works were constructed, we have been obliged, in dealing with "Pressing," to take an approximate average figure for this item, viz. 9d. per ton of pressed cake containing 55 per cent. of water, or 2d. per ton of sludge containing 90 per cent. of water.

† This figure is an estimate.

MANURIAL VALUE OF SEWAGE SLUDGE.

253. Opinions in regard to the manurial value of sludge were of so conflicting a character that we thought it advisable to institute some accurate experiments with various sewage sludges.

Through the kindness of the Board of Agriculture and Fisheries, these experiments were carried out at several collegiate centres under their supervision.

The experiments took the form of three series as follows :—

Series 1.—Experiments with mangolds and swedes at five collegiate centres, under the supervision of Dr. W. Somerville.

Series 2.—Experiments with grass at eight collegiate centres under the direction of Professor Middleton, and at Woburn by Dr. J. A. Voelcker.

Series 3.—Pot-culture experiments at Woburn by Dr. J. A. Voelcker.

The reports on these experiments are given in Appendix VIII.

In all three series of experiments the same sewage sludges were used, and in each case the sludge was artificially dried before being sent to the experimental stations. Its carriage would otherwise have presented much difficulty.

The sludges were derived as follows :—

Sludge No. 1.—*Composite precipitation sludge produced by the Native Guano Co., Ltd., at Kingston-on-Thames* :—

This sludge consists of the precipitate deposited in continuous flow tanks, as the result of adding alumino-ferric, blood, charcoal and clay (together about 50 grains per gallon) to the Kingston sewage, which is mainly domestic in character, but which contains a small proportion of waste liquors from breweries and a gas works.

Having been pressed into cake and then artificially dried at a temperature of about 75° Centigrade, it was stored under cover for some time previous to sampling.

Sludge No. 2.—*Composite precipitation sludge from Dorking, Surrey* :—

This sludge consists of the precipitate deposited in continuous flow tanks as the result of adding lime (10 grains per gallon) and alumino-ferric (5 grains per gallon) to the Dorking sewage, which is almost entirely domestic in character.

It was first pressed into cake and then dried by placing portions of it in thin layers near a boiler. A further quantity of lime, equivalent to about 120 lbs. per ton of pressed cake, was added previous to the pressing.

Sludge No. 3.—*Alumino-ferric precipitation sludge from Chorley, Lancashire* :—

This sludge consists of the precipitate deposited in quiescent settling tanks as the result of the addition of alumino-ferric (9 grains per gallon) to the Chorley sewage, which is domestic in character.

Having been pressed and partially dried under cover, it was further dried by placing it in small quantities on either side of a boiler. Previous to the pressing a quantity of lime, equivalent to 1 cwt. per ton of pressed cake, was added to the sludge.

Sludge No. 4.—*Composite precipitation sludge from Leeds, prepared by Alton's process* :—

This sludge consists of the precipitate deposited in a continuous flow tank as the result of adding calcium phosphate (4 to 5 grains per gallon) in acid solution and subsequently lime (about 1 grain per gallon) to the Leeds sewage, which is rather dilute and contains a considerable proportion of waste liquors from various manufactories.

The wet sludge was first drained in a lagoon and afterwards dried artificially by placing it near a boiler.

SLUDGE No. 5.—*Septic tank sludge from Leeds :—*

This sludge consists of the deposit in an open septic tank which had been receiving Leeds sewage for a period of three years. The flow of sewage into the tank during this time was sufficient to fill it once every twenty-four hours. The wet sludge was first drained in a lagoon and afterwards dried artificially by placing it near a boiler.

SLUDGE No. 6.—*Settled sewage sludge from Leeds :—*

This sludge consists of the deposit settling in the second of a series of continuous flow subsidence tanks used at Leeds for the treatment of the main flow of sewage. The wet sludge was first drained in a lagoon and afterwards dried artificially by placing it near a boiler.

SLUDGE No. 7.—*Composite precipitation sludge from Glasgow (Dalmarnock), known as "Globe Fertilizer" :—*

This sludge consists of the precipitate deposited in continuous flow tanks as the result of the addition of persulphate of iron (8 grains per gallon) and lime (4 to 5 grains per gallon) to the Glasgow (Dalmarnock) sewage, which contains much manufacturing waste.

The sludge was first pressed and then artificially dried at a temperature of 65° to 75° Centigrade, and finally passed through a pan mill.

The chemical compositions of the sludges used in the experiments are given in the Reports, but we may say here that No. 1 sludge contained the most nitrogen and phosphoric acid, and Nos. 2 and 4 the most lime.

SERIES 1.

Dr. Somerville's Experiments with Turnips, Mangolds, and Swedes.

254. Table I. gives the names of the five experimental stations where this series of experiments was carried out, together with the nature of the soil and the crop grown.

TABLE I.

Place.	Nature of Soil.	Crop Grown.
Rothamsted Experimental Station (Mr. G. D. Hall)	Strong flinty loam overlying chalk.	Mangolds.
Agricultural Department, Cambridge University (Prof. Middleton).	Moderate gritty loam overlying gault.	Mangolds.
Agricultural Department, Leeds University (Prof. Seton).	Strong drift soil overlying the coal measures.	Swedes.
South-Eastern Agricultural College, Wye (Prof. Dunstan).	Strong flinty loam overlying chalk.	Swedes.
Glasgow and West of Scotland College of Agriculture (Prof. Wright).	Strong loam on the carboniferous formation.	Turnips.

The scheme of the experiments was as follows :—

At each station twenty-two plots in duplicate, each $\frac{1}{40}$ of an acre, were selected.

It was decided to use, as far as possible, 40 lbs. of nitrogen and 36 lbs. of phosphoric acid per acre, and 2,072 lbs. of sludge No. 1 were required to supply these amounts. Since the other sludges contained less nitrogen and phosphoric acid than No. 1, 2,072 lbs. did not in their case supply as much as 40 lbs. nitrogen and 36 lbs. phosphoric acid. It was obviously impossible to apply equal quantities of the manurial constituents from all the sludges, while it was also inadvisable to attempt to get over this by the addition of artificial manures. On the first seven duplicate plots an amount equal to 2,072 lbs. per acre of each of the sludges was therefore used. Plots 8*a* and 8*b* received an amount equal to half the above quantity per acre of No. 1 sludge (*i.e.*, 1,036 lbs. per acre), Plots 9*a* and 9*b* received no sludge, and Plots 10*a* and 10*b* received 3,108 lbs. per acre of No. 1 sludge. The other twelve duplicate plots were used for comparative experiments with No. 1 sludge mixed with either sulphate of ammonia, superphosphate, or both, and also for experiments with sulphate of ammonia, superphosphate and fish meal, either together or alone.

The whole of the experimental area received an equal dressing of potash salt, supplying 30 lbs. of potash (K_2O) per acre :—

"The season was somewhat abnormal in character and, on the whole, not very favourable to the action "of manures. From the Midlands northwards the early part of the summer was characterised by great "deficiency of rain, with the result that seed germinated badly and young plants received a check in growth. "At Leeds the root crop on the experimental area was a total failure, so that no figures are available from "this centre.

"At the other centres the yields were fair, being above the average at Cambridge and below the average "at Glasgow."

255. From the results obtained with given weights of nitrogen and phosphoric acid added in the form of artificial manures, Dr. Somerville determines the sensitiveness of the soil to manurial treatment, showing :—

(1) That nitrogen alone (sulphate of ammonia), unsupported by phosphates, produced no positive result at any of the centres, so far as turnips and swedes are concerned. On the other hand, with mangolds at Rothamsted and Cambridge a large increase was obtained.

(2) That the use of 20 lbs. of nitrogen (sulphate of ammonia) per acre, together with phosphoric acid in the form of superphosphate, produced a marked increase of crop in every case.

(3) That 18 lbs. per acre of phosphoric aid (as superphosphate) alone produced no increase of crop, while, with the exception of Wye, 36 lbs. of phosphoric acid per acre produced an increase at all the centres.

Comparing the results obtained with sludge No. 1 alone and mixed with either superphosphate or sulphate of ammonia, he shows :—

(1) That the phosphate of the sludge is less active than the phosphate in the superphosphate, because the addition of a further quantity of phosphoric acid in the form of superphosphate produced a greater relative effect in the former case than the latter.

(2) That there are similar indications with regard to the nitrogen of the sludge.

From the direct comparison of the effects of equal weights of nitrogen (20 lbs. and 40 lbs. respectively) and phosphoric acid (18 lbs. and 36 lbs.) derived from sludge No. 1 and from sulphate of ammonia with super-phosphate and with fish meal, Dr. Somerville shows that the sludge-grown crop is in nearly every case considerably inferior in weight to the crop grown with artificial manure. In several cases the sludge-grown crop was smaller than the crop grown on the unmanured plot (No. 9).

In comparing the results obtained with all seven sludges, he says :—

"Taking the average of all the centres and the average of the seven plots that got 2,072 lb. per acre of "sludge, we find that the yield works out at 19 tons 7 cwt. per acre, which is practically a ½ ton less than "the average yield on the unmanured plot (No. 9). Or, looked at from another point of view, it will be "seen that the highest yield of any of the sludges is that of No. 2 (Dorking) on Plot 6, where it amounts "to 20 tons 5¾ cwt., a figure that is lower than the average yield on any of the plots receiving artificial "manure."

Dr. Somerville's general conclusion is as follows :—

"So far as these experiments go, they show that in the season of 1905 none of the sludges experi-"mented with produced any consistent manurial effect on the growth of turnips, swedes, or mangolds. Al-"though the season was not a good one for the growth of the root crops, it permitted artificial manures to "exert a considerable influence upon the yield of this crop. We would, therefore, appear to be justified in "drawing the conclusion that the nitrogen and phosphoric acid of sludge are in a much less available form "than the same substances in sulphate of ammonia, superphosphate, and fish meal."

In view of the difficulty of the whole subject, it was thought desirable to continue the experiments for another year, this time with hay as the crop to be grown.

SERIES 2.

(a) *Experiments with Sewage Sludge upon Hay, under the Supervision of Mr. T. H. Middleton.*

256. The general scheme of this series of experiments was similar to that of Series 1, except that eight centres were chosen and the crop grown was hay.

At most of the centres twenty-five plots of $\frac{1}{40}$ of an acre each (not in duplicate) were used, but at Cambridge there were thirty-four plots.

The first seven plots received equal weights of the seven sludges; Plots 8, 9, and 11 different weights of Sludge No. 1; Plots 10 and 23 were unmanured; Plots 12, 13 and 14 received No. 1 Sludge with various artificial manures; Plots 15 to 22 combinations of artificial manures alone, while Plots 24 and 25 received lime alone. The artificial manures employed in this instance were basic slag and sulphate of ammonia.

The sludges were the same as in Series 1, but made a year later: as will be seen from the chemical analyses, their composition varies slightly. Sludge No. 1 again contained the most nitrogen and phosphoric aid, and Nos. 2 and 4 the most lime.

Table II. gives the names of the centres at which the experiments were carried out with the nature of the soil and the condition of the meadow land.

TABLE II.

Centre.	Nature of Soil.	Condition of Meadow Land.
(1) The North of Scotland College of Agriculture, Aberdeen.	Poor, wet clay.	Field had been in grass for six or seven years, but was in extremely poor condition.
(2) The West of Scotland College of Agriculture, Glasgow.	Heavy clay.	Grass in its first year.
(3) The Armstrong College, Newcastle-on-Tyne.	Clay loam.	Field had been in grass for about thirty years.
(4) The University, Leeds.	Medium loam.	Old meadow land.
(5) The University College of North Wales, Bangor.	Gravelly soil.	Old meadow land.
(6) The Agricultural Department, Cambridge University.	Medium, but sticky loam.	Pasture of fifteen to twenty years' standing.
(7) The Rothamsted Experimental Station, Harpenden, Herts.	Heavy clay loam.	Old meadow land.
(8) The South-Eastern Agricultural College, Wye, Kent.	Somewhat stiff loam overlying chalk.	Pasture of some years' standing.

257. Mr. Middleton's report should be referred to, but we may say that the broad results show that at the northern stations, where the wet summer was favourable to slow-acting manures, the application of sludge seems to have been useful.

In the South of England, where the hay is cut much earlier, the sludges produced no results whatever.

Speaking generally, the two sludges containing the most lime, viz., Nos. 2 and 4, gave the best results among the sludge grown crops.

In a general survey of these experiments and the experiments of Series 1, Mr. Middleton says:—

"The figures obtained in this experiment and in the corresponding experiments made last year are not "of a satisfactory character, and do not permit of any conclusions as to the relative money values of sludge "and artificial manures.

"The only definite conclusion which may be stated is that, for root crops and grass, the action of the "nitrogenous and phosphatic constituents of sludge is very slow, as compared with the effect produced by "nitrogen and phosphates supplied in ordinary artificial manures.

"For such crops as mangolds, potatoes and swedes, which have a short period of growth and require "quick acting manures, sewage sludges would not appear to be well adapted, and if they are employed they "should be applied in tons rather than in hundredweights per acre.

"On the other hand, although these experiments do not supply the evidence, it seems likely that sludge "used in proper quantities would form a good dressing for the slow growing plants of many permanent pastures "and meadows.

"Sludge is unlikely to give satisfaction on the very poor clay-soil pastures which are so much benefited "by basic slag, but for old grass land of moderate quality it should prove useful."

It is instructive to note the indication that sludges produced by precipitation with lime are probably more valuable as manures than sludges derived from precipitation with salts of alumina or iron. As is well known, phosphate of lime is much more readily assimilated by plants than phosphate of iron or alumina.

This series of experiments upon hay is being continued at some of the stations for another year without any fresh application of sludge.

(b) *Experiments with Sewage Sludge on Grass Land at Woburn, by Dr. J. A. Voelcker.*

258. These experiments were on much the same lines as those carried out under Mr. Middleton.

Eleven plots of $\frac{1}{40}$ of an acre were marked out in a field that had been long in grass, but which could only be described as of moderate quality. The field is on the junction of the Lower Greensand with the Oxford Clay, the soil partaking of the character of both formations.

The first seven plots were respectively dressed with each of the seven sludges in quantity sufficient to supply 40 lb. of nitrogen per acre, Plots 8, 10 and 11 received ordinary mixtures of artificial manures, and Plot 9 was left unmanured. Plots 8, 10 and 11 also received a dressing of lime. Exactly the same sludges were used as in Series 2 (*a*).

"All the sludges, with the exception of Nos. 2 and 4 (which were rather 'sticky' in nature, and would "in practice be rather difficult to sow), were in fair condition and could be easily manipulated. Very little "rain fell during the months of February and March, the recorded rainfall at Woburn being only 0·99 inch "for February and 0·83 inch for March. In April, however, there was much more, and on April 12th 0·44 "inch of rain fell, this being the first real washing which the manurial applications received. This fact "and the absence of warmth by which the season was marked no doubt militated much against the sludges "increasing any decided benefit, and it is, indeed, very probable that the results now recorded cannot fairly "be taken as a guide to the real or relative values of the sludges. In all experiments conducted on grass land "it is unfair, and often misleading, to take the results of a single year as conclusive, and especially is this the "case when an abnormal season like that of 1907 enters into the calculation."

When the hay was cut on July 15th it was found that there was little difference in weight of crop from any of the first six plots, the produce ranging from about 2 tons per acre (Plot 1) to about 2 tons 4 cwt. per acre (Plot 4). Plot 7, receiving Sludge No. 7; Plot 8, receiving superphosphate, 3 cwt. per acre and lime 5 cwt.; and Plot 9, which received no manure, gave from about 2 tons 5 cwt. (Plot 8) to about 2 tons 7 cwt. (Plot 7) of hay.

Plot 10 (superphosphate 3 cwt., lime 5 cwt., sulphate of ammonia $\frac{3}{4}$ cwt.) gave about 2 tons 8 cwt., and Plot 11 (sulphate of ammonia $1\frac{1}{2}$ cwt.), 3 tons 3 cwt.

259. Summarising these results Dr. Voelcker says:—

"There is, I think, little more to be said than that, for all practical purposes, the sludges did not 'tell' "during this season, but that they require longer time to show their influence, and that the only clear benefit "was to be traced to the more quickly acting (because more soluble) material, sulphate of ammonia. That "even this increase will, in the end, be a beneficial one, is by no means certain, for the mere 'flushing' of a "grass field to give an extra cut for hay by no means results necessarily in the improvement of the pasture "permanently. Here, again, continuation of the experiment for other years is called for."

SERIES 3.

Pot Culture Experiments at Woburn by Dr. J. A. Voelcker (1907).

260. In addition to the foregoing experiments with grass, Dr. Voelcker also carried out a detailed series of experiments with wheat at the Woburn Pot Culture Station, experiments which involved much care and trouble.

The same seven sludges were used.

The experiments were divided into three groups:—

(1) A comparison of the manurial effect, on the wheat crop, of one kind of sewage sludge as against another, when these were respectively applied in quantities calculated to supply 40 lbs. of nitrogen per acre.

(2) A comparison of the effect of each individual sludge with that of an artificial dressing composed of superphosphate, rape dust and lime, calculated to supply the same amounts of phosphoric acid, nitrogen and lime as did the corresponding sludge.

(3) A comparison of the cost of increase of crop obtained by the addition of sludge and by artificial manures of known cost. In this experiment the sludges were used in equal weights (2 tons per acre) and compared with dressings of artificial manures such as a farmer would be likely to use.

Every experiment was carried out in triplicate, the plan being to grow the wheat in pots of certain size filled with soil of known composition. In filling the pot the last fifth of the soil was thoroughly incorporated with the sludge or artificial manure used in the experiment. The pots held 40 and 32 lbs. of soil. Control experiments for each size of pot were also made at the same time.

When the pots were all filled, on December 5th, 1906, they were each sown with twelve seeds of wheat, the young plants being thinned out to six in each pot on April 11th, 1907. As regards the plants removed at the time Dr. Voelcker says :—

"[. . . a comparison of the rootlets of the plants then removed showed very little difference between "one sludge and another, but in each case the artificial equivalents had given the larger and stronger root "growth."

"About April 22nd the first change in appearance showed itself, the sludge grown plants being then "slightly in advance of the untreated ('control') ones, and the flag presenting a darker colour. The plants "of Sludge 1 and 4 were the best of the series. On April 25th the top dressing of sulphate of ammonia was "applied in experiment 3.

"By May 24th further differences were noticeable; the 'equivalents' were in most cases rather stronger "than the corresponding sludges. Of the sludges, No. 2 alone seemed no better than the untreated lot, the "others generally showing improvement. Growth was rapid from now, and in each case the 'equivalents' "went to the front, and by June 20th Sludge No. 2, which up to then had been behind the others, now shot "ahead and was the best of the sludges. Sludges 4 and 6 had very irregular plants. As the ripening pro-"ceeded, the most noticeable point was that the straw was distinctly shorter in the case of the 'equivalents' "than with the sludges themselves; this held good in every case. The untreated lots ripened off first, then "the sludges, and lastly the equivalents. Photographs and measurements of the plants were taken just before "harvesting, this latter being done on August 28th, the corn being subsequently threshed out and weighed."

261. Having set out the results in tabular form and examined the results in detail, Dr. Voelcker draws the following conclusions :—

"(1) That the different sewage sludges, when used in sufficient quantity to supply 40 lbs. "of nitrogen per acre, are capable of increasing the yield of both corn and straw by 10 to 12 per "cent. above the unmanured produce.

"(2) That 'artificial equivalents' of the different sewage sludges applied as above will give "rather better results, the increase in corn and straw being 16 to 17 per cent. over the unmanured "produce."

"(3) That the tendency of the use of sewage sludges is to produce a greater length of straw."

"(4) That as between different sludges, those have done the best which contain the most "moisture and the most lime."

"(5) That the value of the sludge does not turn mainly upon the amount of nitrogenous organic "matters contained, but that these may, indeed, be in a form incapable of ready assimilation and "requiring lime for their decomposition."

"(6) That from a practical point of view none of the sewage sludges used would be worth 10s. "a ton on the farm for wheat-growing purposes."

262. Acting on the suggestions of Mr. Middleton and Dr. Voelcker, we have decided to continue these experiments for another year. The indications are that the manurial constituents of sewage sludge act much more slowly than those of ordinary artificial manures, and for this reason the second year results may be of considerable importance.

Unit for unit the nitrogen and the phosphoric acid of sludge seem to be of less value, manurially, than the nitrogen and phosphoric acid of artificial manures; at any rate so far as the first year of application is concerned. It also appears that sewage sludge is not a suitable dressing for quickly growing plants, unless it is applied in very large quantities per acre.

The important practical consideration, however, is not whether the manurial constituents of artificial manures are, unit for unit, more valuable than the manurial constituents of sewage sludge, but whether a given increase of crop can be produced more cheaply with sewage sludge than with artificial manures. Sewage sludge has undoubtedly a manurial value, but the manurial constituents being of necessity mixed with such a large proportion of grit, etc., the question of its economic use as a manure depends, to a large extent, upon the cost of carriage.

In the case of sewage sludge, likely to contain anthrax spores, it would of course be unwise to apply it to land. It would, however, be only in rare cases that such spores would be apt to be present.

SLUDGING OF MILL DAMS.

263. Our attention has been drawn to the evils attending the practice of the sludging of mill dams on rivers, and, although the matter is not directly within our terms of reference, we thought it desirable to take some evidence in regard to it, as it was alleged that the practice frequently gave rise to serious nuisance.

Many of the rivers in this country, particularly in Cheshire, Lancashire, and Yorkshire, are largely used by manufacturers for power and other purposes, and to facilitate the use of the water for such purposes, dams or reservoirs are constructed either in the bed of the stream itself, or near thereto.

In course of time, the mill dams become silted up with solid matters which are brought down in suspension by the stream, and which, owing to the velocity of the stream being reduced, settle in the mill dam. It is necessary to empty these solid matters out of the mill dams from time to time, and the evidence shows that when the accumulations are sent down the river in bulk serious pollution may take place and a nuisance may be caused. The liability to nuisance is of course greater in the case of rivers which, in their course above the mill dams, receive polluting matters such as sewage and manufacturing effluents, but it was represented to us that nuisance also occurs, though in a lesser degree, on rivers which are not so polluted.

Somerville, 20230–4, 20254–5. Tatton, 20264. Halliwell, 20477–86. Wilson, 23915, 23935–6. Tatton, 20265–73. Wilson, 23934.

The witnesses whom we examined specially in regard to these matters were :—

- Mr. Herbert Hughes, C.M.G., Clerk of the Millowners' Association of the River Don.
- Mr. J. Selwyn Rawson, Millowner.
- Mr. A. F. Somerville, Chairman of the Sanitary Committee of the Somerset County Council.
- Mr. R. A. Tatton, Chief Inspector of the Mersey and Irwell Joint Committee.
- Mr. E. Halliwell, Chief Inspector of the Ribble Joint Committee.
- Mr. H. Maclean Wilson, Chief Inspector of the West Riding of Yorkshire Rivers Board.

From the evidence of these witnesses, we find that there are three principal methods of removing the accumulations of solid matters, or sludge as it is termed, from dams, namely, (*a*) by opening the sluices and allowing the accumulated water to flush out the sludge; (*b*) by turning the water of the stream through the dam and employing men to push and carry the sludge into the current of water, by which it is washed out of the dam into the stream; and (*c*) by running the water out and wheeling the sludge to a tip outside the dam.

264. The main provisions of the general law affecting this matter are contained in the Rivers Pollution Prevention Act, 1876. There are, besides, two special Acts, namely, the Mersey and Irwell Joint Committee Act, 1892, in force in the area under the jurisdiction of the Mersey and Irwell Joint Committee; and the West Riding of Yorkshire Rivers Act, 1894, in force in the area under the jurisdiction of the West Riding of Yorkshire Rivers Board.

By Section 2 of the Rivers Pollution Prevention Act, 1876, it is provided that "every person who puts or causes to be put or to fall, or knowingly permits to be put or to fall into any stream, so as . . . . . to interfere with its due flow, or to pollute its waters, the solid refuse of any manufactory, manufacturing process or quarry, or any rubbish or cinders, or any other waste or any putrid solid matter, shall be deemed to have committed an offence against this Act." By Section 17 the Act is not to apply to or affect the lawful exercise of any rights of impounding or diverting water; and by Section 20, the term "solid matter" if not inconsistent with the context, does not include particles of matter in suspension in water.

The effect of these provisions upon the sludging out of mill dams has been the subject of a judgment in the Court of Appeal in the case of Ribble River Joint Committee *v.* Halliwell. The respondent owned a mill on the river Darwen, and he had from time to time been accustomed to divert the water, which was polluted with

vegetable substances, into a reservoir. The water was impounded in the reservoir, cleared, run off, and then used for condensing purposes. A large deposit was left at the bottom of the reservoir, and from time to time sluice gates were lifted and the deposit was discharged into the river. The matter so discharged was putrid, and it no doubt polluted the river.

The Court of Appeal held that the lawful exercise of the right to impound and divert water, which was protected by Section 17 of the Act of 1876, necessarily implied a right to return the water after it had been used for the purposes for which such right of impounding and diverting was so exercised; and that if, by the impounding, solid matter which was brought down in suspension by the stream was allowed to settle and become putrid, the return of the water, together with such putrid matter, was not an offence under Section 2 of the Act.

265. In the Mersey and Irwell Joint Committee Act, 1892, the prohibition against the putting of solid matters into a stream is extended to "sludge"; but it is provided that no person shall be deemed to have committed an offence against the Act for constructing in or across any "river or stream any . . . dam . . . which but for the passing of the Act he would have a legal right to construct," or "for putting into any such river or stream any sand or gravel or other natural deposit which shall have flowed from or been deposited by the current of any such river or stream."

So far as we are aware, the effect of the Mersey and Irwell Joint Committee Act has not been determined by the High Court; but it was stated by Mr. Tatton, then Chief Inspector of the Joint Committee, that proceedings had been taken under the Act in seven cases against millowners on polluted streams for sludging out mill dams, and that convictions were obtained in all these cases.

tton, 20305.

266. The West Riding of Yorkshire Rivers Act, 1894, follows closely the Mersey and Irwell Act, but is, if anything, somewhat stronger. For in addition to "sludge," the West Riding of Yorkshire Act expressly mentions "any rubbish or any deposit in a reservoir, mill dam, water lodge, or pond," as amongst the solid matters which may not be put into a river; and, while it contains the proviso that no person shall be deemed to have committed an offence for putting into a river or stream any sand or gravel or other natural deposit which shall have flowed from or been deposited by the current of the river or stream, it further provides that the sand or gravel or other natural deposit so put back into the stream shall not interfere with the due flow of or pollute the waters of such river or stream.

The West Riding Act has been before the High Court in the case of West Riding of Yorkshire Rivers Board *v.* Goldthorpe and another, which was an appeal by the Rivers Board from the decision of the Quarter Sessions dismissing a case in which a millowner was proceeded against for putting solid matter into a stream. From the report in *The Times* of June 9th, 1898, we gather that the process of the respondents was to collect in the mill dam the water that worked the mill by reason of which a deposit was created. Periodically this deposit was shovelled out into the stream and allowed to be washed down. Evidence was given that as much as 300 tons in one day was thus sent down, and a sample of dark coloured water was put in in evidence. The Court held that the section of the Act prohibiting the putting of solids into a stream did not apply to "cleaning out" a natural deposit of a mill dam. Day, J., stated "that was a natural deposit ordinarily associated with a mill pond when the water was torpid for a certain time. This was not an offence under the section, and, if it were, it would come within the exception."

We may also refer to another action under the West Riding of Yorkshire Rivers Act, viz., West Riding of Yorkshire Rivers Board *v.* Rawsons (1903). The respondents were the owners and occupiers of a mill situated on the bank of a river. Adjoining the mill was a large dam fed by a goit from the river and a tributary stream and having an outlet at the other end into a lower part of the river. The sewage from some 400 houses, besides the treated trade effluents of six mills, entered the river above the dam. Owing to the waters being impounded in the dam, a deposit of mud and sludge had formed in the basin of the dam. The respondents, in order to get rid of the mud-sludge and deposit, opened the sluice at the outlet of the dam and turned the whole of the waters of the river through the dam, while men with spades conveyed and scraped the mud, sludge and deposit into the current so made when it was carried in suspension through the outlet, making the river muddy and unfit for any purpose.

It was held that the respondents had committed no offence under the Act. In the course of his judgment, Wills, J., stated, "under the Act applicable to the present case the sludge is prohibited from being sent out, but, by reason of what has been done, the sludge before anything has been sent out has ceased to be sludge, or has been converted into a very mild decoction." This had reference to the fact that a sample of the water taken at the outlet during the sludge operations was analysed and found to consist of slightly over 99½ per cent. of liquids and less than half per cent. of solids in suspension.

267. It was clearly the intention of the two Rivers Boards, in promoting their special Acts, to obtain power to prevent millowners from turning into the river the solid matters which had been deposited in mill dams, and it was urged by some of the witnesses that the general law should be altered so as to prohibit the scouring out of the sludge into the river, save perhaps in exceptional cases, and that the manufacturer should be required to remove the sludge on to land. Mr. Maclean Wilson, representing the West Riding of Yorkshire Rivers Board, stated that, on the whole, this was the more common practice in the West Riding, and that therefore it must be regarded as a financially practicable method to adopt. Mr. Tatton, Chief Inspector of the Mersey and Irwell Joint Committee, and Mr. Halliwell, Chief Inspector of the Ribble Joint Committee, expressed a similar view.

Somerville, 20250. Tatton, 20286–7 20318–9. Halliwell, 20503–5. Wilson, 23918–21, 23939–44, 23939–42. Tatton, 20331–; Halliwell, 20505–6.

On the other hand, Mr. Hughes, representing the Millowners' Association of the River Don, contended that the cost of removing the sludge on to land would in some cases be absolutely prohibitive, and this view was supported by the evidence of Mr. Rawson, a millowner. It was further pointed out that in some cases the situation of the mill dam would render it impracticable to remove the sludge on to land.

20124. 20183–99. Rawson, 20184– Halliwell 20515–7.

268. We are satisfied that the discharge of sludge from mill dams into the river, at more or less lengthy intervals of time, in some cases gives rise to serious evils. While the river could itself deal with the suspended matters as they flow down from day to day, it cannot cope with the accumulation of such matters when these are discharged altogether over a short period.

At the same time it must be remembered that in numerous case millowners have had the unrestricted right for many years to empty the sludge from their dams into the river, and that any undue interference with this right might seriously affect industries.

Looking to all the circumstances, and having regard to the evidence given on behalf of millowners, we do not consider that the practice of sludging mill dams by turning the accumulations into the stream should be absolutely prohibited by law in every case without regard to the local circumstances. We are of opinion, however, that in most cases it would be financially practicable for the millowner to remove the sludge on to land or to adopt some other means of disposing of it, and in such cases the millowner should not be allowed to turn it into the stream if, by so doing, a nuisance would be caused.

Recommendation.

269. We recommend that in any case in which the Rivers Board should be of opinion that the sludging of a mill dam by turning the accumulated sludge into the stream would give rise to nuisance, and that it would be financially practicable for the mill owner to adopt some other method of cleansing the dam, the Rivers Boards should be empowered, by notice, to direct the millowner not to turn the sludge into the stream.

It should be provided that any millowner deeming himself aggrieved by such a direction, might, within some fixed period, appeal to the Central Authority. The decision of the Central Authority should be final.

Should any cases arise in which it is important that the sludge should not be turned into the stream, but in which the Rivers Board are of opinion that the cost of adopting any other method of cleansing the dam would be prohibitive to the millowner, we recommend that the Rivers Board should be empowered to represent the case to the Central Authority, and that the Central Authority should be empowered, after due inquiry, to direct that the sludge shall not be turned into the stream. If the Central Authority should be satisfied that the cost of adopting some other method of cleansing the dam would be greater than the millowner could be reasonably called upon to bear, they should be empowered to direct that a portion of the cost should be borne by the local authorities whose districts would be benefited.

PART V.—GENERAL.

EFFECT OF TRADE EFFLUENTS ON SEWAGE PURIFICATION.

270. All the trade effluents of which we have had experience interfere with or retard processes of purification to some extent, but we are not aware of any case where the admixture of trade refuse makes it impracticable to purify the sewage either upon land or by means of artificial processes, although in certain extreme cases special processes of preliminary treatment may be necessary.

In the following cases, which we have investigated more or less fully, some modifications have had to be adopted in consequence of the presence of trade refuse.

Burton-upon-Trent.—Brewery refuse.

Here the sewage consists mainly of brewery refuse, the sewage proper constituting only about one-fifth part of the whole. We are not aware whether artificial processes of treatment have been tried with the Burton sewage; but, for its treatment on land, the addition of a very large quantity of lime has been found necessary (40 to 50 grains per gallon), otherwise the decomposition of the sewage gives rise to the production of much sulphuretted hydrogen, causing great nuisance. With carefully regulated addition of lime, treatment on land appears to be successful in producing a good effluent.

Bradford.—Wool-scouring liquor.

The sewage of Bradford contains a large proportion of wool-scouring liquors, which have the effect of making it abnormally alkaline and very greasy. A special preliminary process of precipitation has therefore been found necessary, viz., the "cracking" of the sewage with sulphuric acid. The fats which are thus set free are extracted from the precipitated sludge by pressing hot, and by distillation of this pressed sludge under reduced pressure. The precipitation liquor after the addition of sulphuric acid can be successfully treated on percolating filters at rates of from 50 to 100 gallons per cube yard per day, notwithstanding that it is often distinctly acid as it goes on to the filter. It may be added that the effluent from the filters is usually neutral or slightly alkaline.

Rochdale.—Wool-scouring liquor, waste liquor from fellmongers, rubber-recovery waste.

At Rochdale, as at Bradford, the sewage is often rendered very alkaline and greasy by the discharge of wool-scouring liquor. At such times sulphuric acid in addition to alumino-ferric is used as a precipitant; otherwise the tank liquor obtained is unsatisfactory and badly settled. The sewage after precipitation is successfully treated, either upon filters, or upon land.

It is interesting to note that the strong alkaline sewage at Rochdale can be successfully treated, without any neutralisation, by septic tanks, followed by Whittaker percolating filters.

Wolverhampton.—Waste liquors from galvanising works.

Owing to the discharge of the "used-out" liquors and wash water (which contain a large quantity of ferrous iron in acid solution) from the vats at the galvanising works in the town, the Wolverhampton sewage is often mixed with such a large quantity of this liquor that it is then necessary to increase the quantity of lime which

is used as a precipitant in order to obtain good settlement in the tanks. If sufficient lime is added, the iron in the sewage helps the precipitation. The tank liquor is successfully treated over land, and it has also been shown, by experiment, to be easily amenable to treatment on bacteria beds.

There are many similar cases; but those cited are, perhaps, sufficient to show that trade effluents may render necessary modifications in the ordinary processes of purification.

271. These cases may, we think, be regarded as more or less exceptional. Usually we find that the amount of trade effluent is not sufficiently large to make any material modification of the *process* necessary, though of course the increase in volume of the sewage to be treated may necessitate an enlargement of the filtering area. The following are cases of this kind:—

Birmingham.—Various manufacturing liquors.

The Birmingham sewage, notwithstanding the considerable proportion of various manufacturing waste liquors which it contains, can be successfully treated upon land or upon artificial filters, after ordinary preliminary settlement and septic tank treatment.

Manchester.—Various manufacturing wastes, including many tar products.

Here part of the sewage is being successfully treated on a large scale by means of septic tanks and contact beds.

Leeds.—Wool fibre, dye waste, tannery and iron liquors.

The fibrous nature of the suspended matter in the Leeds sewage and the amount of finely divided and colloidal iron compounds which it contains seem to be the main causes which render the settlement—either by septic tank treatment or sedimentation, or even by precipitation—more difficult, and the danger of filter clogging much more serious, than would be the case if these waste products were absent. The trade effluents in general also seem to have the effect of inhibiting, to some extent, the action of the nitrifying organisms in the biological oxidation processes at Leeds, for it has been noticed that filters take an exceptionally long time to mature there.

The experiments at Leeds, however, have shown that it is possible to produce good effluents by various processes, and that—with careful selection of the materials—clogging can be prevented long enough to make it practicable to treat the sewage by artificial filtration.

Maidstone.—Brewery and tannery waste.

The Maidstone sewage is frequently mixed with large quantities of the waste liquors from breweries and tanneries. At such times the liquid resulting from the tank treatment after precipitation with lime is organically stronger and less well settled than at other times. The trade effluents at Maidstone also appear to have the effect of increasing the nuisance from the tanks, for it has been noticed that when these liquors are present the smell is much greater. Experiments, worked partly under our observation for this special purpose, have shown that the sewage can be purified to the extent of 88 per cent., calculated on the "oxygen absorbed" in four hours, by double contact filtration, without preliminary treatment in tanks for the settlement of the solids, although only a small quantity (23·7 gallons) can be filtered per cube yard per day.

Yeovil.—Waste liquors from tanneries.

At Yeovil, closed septic tanks and double contact beds appear to be successful in treating a sewage which is often mixed with a large proportion of tannery liquor.

Here the effect may be to require a more frequent cleansing of the tanks and possibly of the filter beds. We have not watched the plant continuously.

York.—Tannery waste and waste-waters from a confectionery works.

After septic tank treatment the York sewage can be successfully treated upon percolating filters at a rate of something like 150 gallons per cube yard per day.

There are a number of such cases, and, indeed, the great majority of sewages from towns with populations from 5,000 upwards are mixed with small proportions of manufacturing wastes. Generally, therefore, we are satisfied that the character and proportion of the trade effluent or effluents in the sewage are not such as seriously to affect any process of purification, though in some cases where it is present in large proportion, or is of a specially refractory character, special means have to be taken to counteract its influence.

At many of the places which we have visited (for example, Birmingham, Bradford, Burton, Burnley, Huddersfield, Leeds, Manchester) the difficulties arising from the admixture of trade effluent with the sewage have been largely overcome as the result of experiments, which have been conducted under the supervision of skilled scientific advisers resident upon the works.

272. Our further experience strengthens the view which we expressed in our Third Report, that, as a general rule, trade effluents should be allowed to enter the sewers, but that the local authority should be given power to require that their admission should be subject to regulation.

NUISANCE FROM SMELL AT SEWAGE WORKS.

273. All sewage works are liable, at times, to give off unpleasant smells, and they should, therefore, be situated away from dwelling houses, wherever this is practicable.

The nuisance is apt to be considerably greater where the sewage contains brewery refuse in any quantity; but, on the other hand, the presence of some trade effluents, such, *e.g.*, as iron salts or tarry matters, tends to render the process of purification less offensive.

The extent of the risk of nuisance depends, however, not only on the character of the sewage, but also on the method of treatment adopted.

Tank Treatment.

274. Septic tank treatment is likely to be more offensive than chemical precipitation or simple sedimentation. During sludging operations all tanks are usually offensive; but septic tanks—unlike other tanks—may give off sulphuretted hydrogen, and probably small quantities of offensive organic sulphides, at other times.

By covering over septic tanks and the feed channels to the filters, the risk of nuisance from the tanks themselves during the period of working is greatly lessened, but the liquor issuing from septic tanks contains a larger amount of sulphuretted hydrogen than other tank liquors, and its subsequent filtration may, therefore, give rise to more nuisance.

Filters.

275. The exposure of a foul smelling liquid to the air is necessarily accompanied by risk of nuisance, and if such a liquid, in the process of distribution, is divided up into small drops or jets, it is obvious that the smell will be greatly intensified.

For these reasons percolating filters are more likely to give rise to nuisance than contact beds, if the liquid to be treated contains offensive gases.

In some cases, septic tank liquor can be treated upon percolating filters without much risk of nuisance, but where the liquor is derived from a strong domestic sewage or a domestic sewage containing brewery or tannery waste, and especially if it is sprinkled or sprayed upon percolating filters, serious smell may occur in the neighbourhood of the works.

At the following places where septic tank liquor is sprinkled upon percolating filters, there is usually a considerable smell in the proximity of the filters:—

*Accrington - -	Strong domestic sewage.
Dorking - - -	Domestic sewage of about average strength.
Guildford - -	Very strong domestic sewage containing brewery waste.
Dorchester - -	Domestic sewage containing brewery waste.

On the other hand the same process does not give rise to any serious complaint at:—

Birmingham - -	Strong sewage containing much manufacturing waste, which includes salts of iron.
Huddersfield - -	Rather weak sewage containing much manufacturing waste, including salts of iron.
Leeds - - -	Rather weak sewage containing much manufacturing waste, including salts of iron.
Hanley - - -	Weak sewage containing a small proportion of manufacturing waste.

Where fresh crude sewage or fresh precipitation liquor is treated upon percolating filters, there is much less danger of nuisance. This is exemplified at the following places:—

Crude Sewage:

Hendon - - -	Domestic sewage of average strength.
Leeds - - -	Rather weak sewage containing much manufacturing waste.

Settled Sewage:

Huddersfield - -	Rather weak sewage containing much manufacturing waste.
Leeds - - -	Rather weak sewage containing much manufacturing waste.
Market Drayton -	Very strong slopwater sewage.

Precipitation Liquor:

Kingston - - -	Domestic sewage containing a small proportion of trade waste.
Dorking - - -	Domestic sewage of about average strength.
Chorley - - -	Domestic sewage of about average strength.
Royton - - -	Domestic sewage.
Normanton - -	Very strong slopwater domestic sewage.
Withnell - - -	Strong domestic sewage, mainly slopwater.

At Horfield, however (strong domestic sewage, partly derived from latrines), where precipitation liquor was distributed by dripping trays upon percolating filters, there was occasionally a very strong local smell upon the works.

276. Our experience leads us to the following general conclusions upon this question:—

That where weak sewage, purely domestic or mixed with manufacturing refuse, is treated either fresh or after chemical precipitation, or even after passing through septic tanks, there is not likely to be any serious smell. If such a sewage contains a small proportion of brewery or tannery waste, however, and is given preliminary treatment in septic tanks, nuisance may possibly arise if the septic liquor is sprinkled or sprayed upon percolating filters.

That where a strong domestic sewage is treated, either fresh or after settlement or chemical precipitation, by sprinkling upon percolating filters, and especially if it is a slopwater sewage, there will not be much danger of nuisance.* On the other hand, if such a sewage is passed through septic tanks, there will be danger of serious nuisance, while if it contains brewery or tannery waste there will be danger of nuisance with any form of preliminary treatment, excepting possibly chemical precipitation.

That with a weak sewage, containing a mixture of trade wastes (especially if iron salts are present), there will be little danger of nuisance, whatever the form of preliminary treatment or final filtration.

That with a strong sewage containing a mixture of trade wastes, there will not be much danger of nuisance, if it is treated by sprinkling upon percolating filters in the fresh state or after simple subsidence or chemical precipitation; but, if it is first passed through septic tanks, there may in some cases be serious danger of nuisance. This was well exemplified in the case of the experimental septic tank at Sheffield, even though the sewage there contained considerable quantities of iron salts.

The risk of nuisance with percolating filters depends to a large extent on the method of distribution adopted, unless the filter is covered in.

277. The following table shows a number of places arranged in the order of "strength" of sewage, side by side with our observations as to nuisance arising from the distribution of the liquid over the filters:—

* This might not hold good in the case of highly ammoniacal sewages.

Place.	Nature of Sewage.	*Calculated strength of sewage.	Nature of preliminary treatment.	Distributor.	Remarks as to smell arising from the distribution.
Places where smell is apparent.					
Rochdale -	Strong domestic sewage, mixed with large quantities of wool-scouring liquor.	203	Septic tank.	Sprinkler.	Considerable smell in neighbourhood of filter.
Caterham -	Very strong domestic sewage, derived mostly from latrines.	195	Septic and "cultivation" tank.	Perforated pipes.	Strong smell in filter house.
Guildford -	Very strong domestic sewage, mixed with brewery waste.	194	Septic tank.	Sprinklers.	Strong smell in neighbourhood of filter.
Accrington -	Rather strong domestic sewage.	121	Septic tanks.	Sprinklers.	Strong smell near filters as a general rule.
Dorking -	Domestic sewage of about average strength.	96	Septic tanks.	Sprinkler.	Strong smell near filters.
Horfield -	Domestic sewage, derived partly from latrines.	88	Precipitation tanks.	Dripping trays.	Occasionally very strong smell near filters.
Knowle -	Domestic sewage.	78	Septic tanks.	Dripping trays.	Occasionally some smell near filters.
Places where little smell is apparent.					
Clifton - -	Very strong slopwater sewage.	247	Settling tanks.	Fine material on surface.	Very little smell from filters.
Normanton -	Very strong slopwater sewage.	235	Precipitation tanks.	Fine material on surface.	Very little smell from filters.
Little Drayton	Very strong slopwater sewage, containing laundry waste.	205	Settling tanks.	Tipping troughs.	Very little smell from filters.
Birmingham -	Strong trade sewage, containing salts of iron.	—	Septic tanks.	Nozzles.	Very little smell from filters.
Leeds - -	Trade sewage, strong as regards suspended matter, but otherwise rather weak.	123	Septic, settling and precipitation tanks.	Sprinklers.	Very little smell from filters.
York - -	Rather weak domestic sewage, but containing tannery waste, etc.	115	Septic tanks.	Sprinklers.	Very little smell from filters.
Hendon -	Domestic sewage of about average strength.	110	No preliminary treatment.	Tipping troughs.	Very little smell from filters.
Chorley -	Domestic sewage of about average strength.	106	Precipitation tanks.	Flushing over fine material on surface.	Practically no smell from distribution.
Dorking -	Domestic sewage of about average strength.	96	Precipitation and settling tanks.	Sprinklers.	Very little smell from filters.
Kingston -	Domestic sewage of about average strength.	94	Precipitation tanks.	Sprinkler.	Practically no smell from distribution.
Salford - -	Trade sewage of about average strength.	—	Precipitation tanks.	Nozzles.	Very little smell from distribution.
Hanley - -	Weak domestic sewage, containing a small proportion of trade waste.	61	Septic tanks.	Sprinklers.	Very little smell from filters.
Prestolee	Very weak slopwater sewage.	28	Septic tanks.	Fine material on surface.	Very little smell from filters.

(* See p. 15 of this report and the memorandum of Dr. McGowan in Appendix IV.)

278. In the whole of our experience with contact beds, we have only observed one case in which any appreciable nuisance arose after the liquor to be treated was in the bed.

In that case the nuisance was, we think, due to overworking, for the smell practically disappeared when the beds were given a short rest.

On the other hand, there is almost always local smell from the channels or feed troughs delivering to a contact bed, when the liquid to be treated possesses a strong smell, and also, in some cases, when the primary bed is being discharged.

At Hampton, during the last year of the treatment of crude sewage upon contact beds, the filling of both primary and secondary beds was attended with local smell. In the case of the primary beds, we think that there would have been serious nuisance if there had been houses in close proximity to the works. In this case, the smell chiefly arose from the settling "bays" constructed on the surfaces of the beds.

At Guildford, Hartley Wintney, Andover, Exeter (Main Works), Ilford, Leeds, Bradford, and Sheffield, we have, on a number of occasions, been aware of considerable local smell arising from feed channels during the filling of contact beds. If steps are taken to obviate this, there is no doubt that contact beds are less liable to give rise to nuisance than any other form of filters.

In connection with the smell which arises from feed channels and distribution pipes, it is of interest to observe that at Ilford and Andover the authorities have recently adopted the plan of covering the channels and laying a few inches of material over the distribution pipes. We understand that this has had the effect of reducing the smell to a very large extent.

An important point which is sometimes lost sight of is that, although the surfaces of contact beds are rich in insect life, it is unusual to see many flies on the beds, whereas percolating filters of coarse or medium material generally swarm with them.

Treatment on Land.

279. Where the soil is fairly porous and the land is not overworked, land treatment of sewage is not, as a rule, offensive.

In certain states of the atmosphere, however, we find that the smell from sewage farms is offensive, and it is therefore important that sewage farms, also, should be kept as far away from dwelling houses as practicable.

Deodorization of Septic Tank Liquors.

280. The use of septic tanks followed by percolating filters, may, in some cases, be the most economical way of treating the sewage, but in view of the greater risk of nuisance from such a combination, it might not be advisable to adopt it in many cases.

The question whether the offensive character of septic tank liquors might be destroyed, arose in the case of Stone, in Staffordshire, where a sewage containing brewery refuse had to be dealt with. In that case it was proposed to overcome the difficulty by the addition to the septic tank liquor of an active chlorine solution, *i.e.*, a solution of alkaline hypochlorite, produced by an electrical process by a company named "Oxychlorides, Limited."

The addition of this chlorine solution clearly lessened the offensive smell of the septic tank liquor, but the question was raised whether it might not also interfere with the subsequent oxidation of the sewage by filtration.

For the purpose of testing this by experiment, two identical percolating filters were provided at the Guildford sewage works, and these were kept under observation for several months by Mr. Carter, Assistant Chemist to the Commission. On to one of these filters was run septic tank liquor alone; on to the other, the same tank liquor, in the same amount, but mixed with varying quantities of the hypochlorite solution.

The results of these experiments showed:—

1. That "35* per cent. to 50 per cent. treatment" with the hypochlorite solution is sufficient to do away with the offensive sulphuretted hydrogen smell of the Guildford septic tank liquor, leaving in its place a comparatively inoffensive odour of spent bleach and fresh sewage.

2. That the addition of this quantity of "oxychloride" in no way interferes with the efficiency of the filter. Indeed, it rather adds to it, by helping to keep down an excess of grey growths on the top of the filter.

3. That a very much larger quantity of oxychloride *may* be added, without any danger to the filter. In other words, there is a large margin of safety, so far as regards the accidental addition of too much oxychloride. Somewhere between "200 per cent. and 500 per cent. treatment" appears to be the limit of the quantity of oxychloride which can be added with safety.

A number of bacteriological examinations were also made in connection with the experiments, and we ascertained that a dose of oxychloride *more* than sufficient to remove a sulphuretted hydrogen smell and kill *B. coli* in the liquid to be treated may be used without prejudice to the purifying ability of a *mature* percolating filter.

A summary of the experiments is given in the accompanying table, and a detailed Report upon them in Appendix IV.

* As to the meaning of this term *see* Mr. Carter's Report, Appendix IV.

GUILDFORD.—TREATMENT OF SEPTIC TANK LIQUOR WITH "OXYCHLORIDE."

Date and Duration of Experiment.	% Treatment	Effect of Treatment as regards Smell of Tank Liquor.	Effect of Treatment as regards Purification by the Filter.	Nitric Nitrogen. Parts per 100,000. Effluent from Untreated Tank Liquor. †	Nitric Nitrogen. Parts per 100,000. Effluent from Treated Tank Liquor. †
				Average.	Average.
Nov. 22nd to Dec. 5th, 1906 (14 days).	25 %	Tank liquor rendered much less offensive, owing to the destruction of about four-fifths of the total sulphuretted hydrogen present.	Quality of the effluent unaffected. The effluent had a slight spent bleach liquor odour.	1·41—2·41=2·07 (8)	1·33—2·74=2·15 (8)
Dec. 6th to 10th, 1906 (5 days).	35 %	This increase of dose was too small to make any marked difference from the 25 % treatment. The tank liquor still possessed a slight septic odour, the sulphuretted hydrogen not being entirely eliminated.	Quality of the effluent unaffected.	1·95—1·98=1·97 (3)	1·95—2·00=1·97 (3)
Dec. 11th to 21st, 1906, and Dec. 31st, 1906, to Jan. 13th, 1907 (25 days).	50 %	This dose completely destroyed all the sulphuretted hydrogen present. The tank liquor possessed a slight fresh sewage smell with an accompanying spent bleach liquor odour, and was not offensive.	Quality of the effluent unaffected.	1·25—2·78=2·13 (15)	1·29—3·63=2·23 (15)
* Feb. 15th to May 13th, 1907 (87 days).	100 %	With this dose there was an excess of oxychloride in the tank liquor going on to the filter. The sewage smell was masked by the spent bleach liquor odour. The average excess of oxychloride was equal to 1·00 parts of available chlorine per 100,000.	Taking the figures for analysis over the whole time, there was very little difference between the quality of the two effluents. This experiment was started in very cold weather, and at first the effluent from the filter taking the treated liquor was inferior in quality to the effluent from the filter taking the untreated liquor. As the weather became warmer, both effluents improved.	0·60—5·82=2·38 (66)	0·21—5·81=2·59 (66)
May 14th to 30th, 1907 (17 days).	200 %	The tank liquor was bleached considerably by this dose.	Quality of the effluent unaffected.	4·10—6·21=4·84 (13)	4·10—6·46=4·92 (13)
May 31st to June 10th, 1907 (11 days).	500 %	This dose bleached the tank liquor to a pale yellowish colour. The average excess of oxychloride amounted to about 12–16 parts of available chlorine per 100,000.	The quality of the effluent was appreciably affected by this dose, both as regards appearance and the amount of Nitric Nitrogen.	4·62—5·98=5·26 (10)	2·90—5·05=4·00 (10)
June 11th to July 12th, 1907 (32 days).	1,000 %	The tank liquor was completely bleached by this dose and possessed a strong spent bleach liquor odour, owing to the large excess of oxychloride (about 30 parts of available chlorine per 100,000).	The quality of the effluent was immediately affected by this dose, the Nitric Nitrogen being reduced by about 50 per cent. In a fortnight it had disappeared entirely and the effluent was very thick and turbid in appearance, and on testing gave a reaction for available chlorine.	4·22—5·85=4·91 (14)	0·00—2·70=1·17 (14)

* From March 5th, 1907, the conclusions have been based on data supplied by Mr. Fieldhouse, Manager at Guildford for Oxychlorides, Ltd.
† Figures in brackets represent the number of samples analysed.

The Oxychloride Company has furnished the following figures as representing the working cost of deodorising 1,000,000 gallons of septic tank liquor by the addition of 6 gallons, 8·4 gallons, and 12 gallons of strong oxychloride, respectively, per 100,000 gallons of liquor:—

Amount of Oxychloride added.	Working cost per million gallons. s.	d.
6 gallons per 100,000 gallons	9	3
8·4 " "	12	2
12 " "	18	6

The capital cost of the plant would be the same in each case. For the Guildford sewage, this was calculated to be £1,220.

281. Of course, there are other ways of providing chlorine, if it should be found that this is the best body to use for the purpose of destroying the offensive character of septic tank liquor.

Our own experiments have shown that the offensive character of Dorking septic tank liquor can be destroyed by the addition to it of 3 grains of lime per gallon. We have also found that the liquor, so treated, could, after a short settlement, be filtered at a considerably increased rate.

Generally, we may say that the risk of nuisance at a sewage works may be considerably lessened by careful selection of the method of treatment and careful attention to details; and that by the adoption of special precautions, methods of treatment, which ordinarily are accompanied by somewhat serious smell, may be rendered almost inoffensive.

SOME OBSERVATIONS ON THE CHOICE OF A METHOD OF SEWAGE TREATMENT.

General.

282. The selection of a method of sewage disposal, and the settlement of details in connection with any method which it is proposed to adopt, should depend primarily on local conditions, and we only propose to indicate in a general way what, in our opinion, should be the guiding considerations.

In a later part of this Report,* we have expressed the view that the degree of purification which should be required in any particular case should depend on local circumstances, and the question which a local authority would have to determine would be in what way the sewage could be most economically purified to the extent necessary. If a sufficient quantity of good land, to which the sewage can flow by gravitation, can be purchased for about £100 an acre, land treatment would, we think, usually be the cheapest method to adopt. Or, if the case were one in which it was necessary to obtain a high class effluent, it might be cheaper to pay a somewhat higher price for good land, rather than to adopt artificial treatment, because effluents obtained from the treatment of sewage on artificial filters, as usually carried out in practice, are generally distinctly inferior to those obtained by the treatment of sewage on good land, and some addition to the ordinary artificial plant would therefore be required. On good land, a sewage of average strength, from which the major portion of the suspended solids have been eliminated by tank treatment, can be treated at about the rate of 30,000 gallons per acre per day, with the production of a high class effluent. If the land available were of only medium quality, capable, say, of treating only half this quantity, its use might still be economical, if it could be acquired at about £50 an acre.

In cases where only clay land was available, we think that it would generally be cheaper and more satisfactory to provide artificial filters.

In considering the question whether land or artificial treatment should be adopted, the situation and levels of the land available are, of course, important factors. And whatever system is adopted, it is essential that the works should be so situated as to be capable of extension.

Selection of an Artificial Process.

283. As regards the selection of an artificial process, the following are the broad generalisations at which we have arrived :—

Tank Treatment.

It has been shown in another section of our Report that, given conditions favourable to each process, there is little difference as regards cost between any of the different forms of tank treatment when the cost of the subsequent filtration is taken into account. For this reason, the selection of the preliminary process should depend mainly upon local circumstances and upon the facilities offered for the disposal of sludge.

If the circumstances were such that considerable quantities of sludge could be easily and effectively disposed of, say, as wet sludge by sending to sea or by trenching in soil, or as pressed cake by sale or gift to farmers, it would probably be best and cheapest to adopt a preliminary process which removed as much of the suspended matter as possible from the sewage. If, on the other hand, it were imperative to have as little sludge and as few sludging operations as possible, then septic tanks or continuous flow settling tanks might be cheaper. The size of the place and the question of smell † are also factors of primary importance in the selection of the preliminary process.

* *See* section of this Report on Standards, p. 217.
† *See* preceding section, "Nuisance from Smell."

Filters.

Single contact beds will, generally, only yield a good effluent where the sewage to be purified is weak, and then only after good preliminary treatment. For the purification of partially settled weak sewage and for well as also for partially settled sewage of average strength, if the case is one in which a good effluent is required, double contact is necessary, while, if a strong sewage has to be purified, triple contact is necessary unless the preliminary treatment is exceptionally good.

In nearly every case a greater rate of filtration can be adopted if the material is arranged in the form of a percolating filter than if it is used in contact beds. The rate of filtration per cube yard in the case of percolating filters may, generally, be double or nearly double that which is permissible in the case of contact beds.

As regards percolating filters, where the liquor to be treated is weak, and the preliminary treatment has effectively removed the greater part of the suspended matter, it is probably best, in most cases, to use fine material arranged in the form of shallow filters.

Where the sewage to be treated is strong, and especially if the preliminary treatment leaves a considerable quantity of suspended matter in the tank liquor, it is best to use deep filters of coarse material.

Where the liquor to be treated contains much suspended matter, it is usually advisable to construct percolating filters of coarse material, *whatever the strength of the original sewage.*

For sewages of about average strength, from which most of the suspended matter has been removed in the preliminary treatment, either coarse or fine material may be used.

It may be added that, with very well clarified weak sewage, filters with a top layer of very fine material, such as sand, can be made to give good results with a rate of filtration of 400 or even 500 gallons per cube yard per day. In this case, however, the material must be washed (*e.g.*, by upward flow of tank liquor) at short intervals of, say, a week.

284. The three appended tables have been prepared to show the kind of results which may be expected by treatment, in various ways, of strong, medium, and weak sewages. The figures, in the majority of cases, are averages from a fair number of samples, and where they are not based on actual observations, they have been arrived at from general experience.

It has been assumed that the sewage does not contain trade waste or any other substance in sufficient quantity to inhibit the action of the micro-organisms, that the works are efficiently managed, and that the filtering material used in the filters has a rough and vesicular surface.

The rates of treatment per cube yard of filter, or per acre of land, which are given are for the dry weather flow, but except in the cases noted on the tables, they are rates which can be doubled during storm times.

The actual size of plant, or area of land, which would be required in any case would depend on the extra amount of sewage which, in the particular case, had to be treated on land or on filters in wet weather.

As we shall subsequently explain,* we think that local conditions should determine what this extra amount should be.

The question of comparative cost of land treatment and artificial treatment has been dealt with in an earlier section of this Report, and also considerations arising out of the risk of nuisance from the different methods of treatment.

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* *See* pp. 209 and 210.

TREATMENT OF STORM-WATER SEWAGE.

285. The proportion of rain-water from a drainage area which reaches the sewers and is conveyed to the outfall depends very largely on local circumstances, and consequently differs at different places.

Where, for example, the greater part of the drainage area consists of roofs and paved roads, the proportion of rain flowing off by the sewers will be greater than where the area chiefly consists of a more or less pervious soil.

Further, the amount of rain reaching the outfall will depend, to some extent, on whether the district is flat or hilly, the gradient of the main and tributory sewers, and what storm overflows are provided.

The system of sewerage will also make a considerable difference to the volume of liquid arriving at the outfall. Where a completely separate system of sewers for surface water exists, there will be only a small increase in volume due to rain; with the partially separate system, there will be a considerable increase; and with the combined system, a still greater increase.

286. At Hampton, which is provided with a separate system of sewers for surface water, we estimated the dry weather flow during the years 1902 and 1903 to be approximately 150,000 gallons per day, and the actual daily flow in all weathers to be about 165,000 gallons on the average—an increase due to rain of 10 per cent. only.

At Horfield, where the drainage area is sewered upon the partially separate system, but where there are no storm-overflows, gaugings over four months (April, May, June and July, 1905) showed the average daily flow to be approximately 62,350 gallons. As the dry weather flow was approximately 38,000 gallons per day, this represented an increase of 64 per cent. on the dry weather flow.

At Little Drayton, where the sewerage is on the combined system, and where there are two storm-overflows, one of which was temporarily dammed for the purposes of our observations, gaugings over three months (January, February and March, 1905) showed that the average daily flow was 15,350 gallons, or about 30 per cent. above the dry weather flow of 12,000 gallons.

At Rhyl, where the sewerage of the area is upon the combined system, and where there were no storm-overflows, gaugings made by Mr. Baldwin Latham for two entire years (1900–1901) gave the following figures. (Report* by Mr. Baldwin Latham to the Commission, June 29th, 1903, pp. 3 and 17):—

Rainfall.	Number of days on which 0·01 inch or more rain fell.	Total flow in sewers.	Dry weather sewage flow, including subsoil water.	Water supply.	Rainfall flowing off (*i.e.*, increase in flow due to rain).	Rainfall and subsoil water.
Inches.		Gallons.	Gallons.	Gallons.	Gallons.	Gallons.
1900 26·52	168	165,683,520	123,281,534	91,438,652	42,401,986	74,244,868
1901 20·46	139	159,161,870	121,825,485	97,385,727	37,336,385	61,776,143

* Appendix V.

The increase of volume in this case, therefore, amounted to an average of 32·5 per cent. on the dry weather flow over the two years.

In his report, Mr. Baldwin Latham gives the following figures for Deal, which was also sewered on the combined system and had no storm-overflows:—

September, 1901, to February, 1903, inclusive.

Rainfall.	Number of days on which 0·01 inch or more rain fell.	Total flow in sewers.	Dry weather flow.	Rainfall flowing off.	Water supply to district.
Inches.		Gallons.	Gallons.	Gallons.	Gallons.
33·525	250	183,996,063	152,883,153	31,112,910	136,059,220

In this case, therefore, the increase was 20·35 per cent. on the dry weather flow.

At Rochdale, which is sewered upon the combined system, where the greater part of the area is paved or roofed, but where some thirteen storm-overflows exist, Mr. S. S. Platt, the Borough Surveyor, by gaugings extending over the year 1904, showed that the increase was roughly 52 per cent. of the mean dry weather flow.

At Oswestry, where the combined system is in use, but where the main storm-overflow is set rather low, Mr. G. W. Lacey, the Borough Surveyor, has found the increase to be about 21 per cent. of the mean dry weather flow. In this case a large quantity of subsoil water gains access to the sewers.

At Chorley, where the combined system is in use, where the main storm-overflow is set at about three times the mean dry weather flow, and where there are two local storm-overflows, the increase is about 45 per cent. In this case a small stream finds its way into the sewers.

In his report already mentioned, Mr. Baldwin Latham gives gaugings of the sewage flow at Croydon for the years 1880 to 1886 inclusive. The figures are summarised in Table 14, p. 28 of the report. From these figures, it will be seen that the increase of flow at that town due to rainfall was only 11·6 per cent. on the dry weather flow in the sewer, as calculated from the water supply. But it should be specially noted that in this case subsoil water is present in the sewers in the proportion of about 1·5 volumes to 1 of sewage, the consequence being that all variations of flow in the sewers are considerably levelled down.

Croydon is sewered upon the partially separate system, and there are no storm-overflows on the system.

287. While it is obvious from these few examples that the circumstances of different places vary considerably, the data available in regard to the effect of storms on the flow of sewage are exceedingly scanty.

In some few places records have been kept for a considerable period of the variation in flow in the outfall sewer and of the volume of sewage treated, but, so far as we are aware, there is little or no information available showing the volumes of liquid which have passed over storm overflows during the same period. It is, however, in some cases enough to do considerable damage to the river.

In the present state of knowledge, we consider that any regulations in regard to the amount of storm sewage to be treated and the method of treatment should be of a tentative character, and that, as regards storm overflows, each place must, to a great extent, be dealt with according to local circumstances. The general principle which should be followed is, we consider, that each local authority should so arrange its sewerage system as to prevent unpurified sewage from passing into the river or stream to an extent likely to cause nuisance.

288. As regards the effect of storms on the character of the sewage, the evidence which we have received, and also our own observations, show that, for the first hour or more, the effect of a storm is to increase the amount of organic matter in solution in the sewage as it arrives at the works, and also very largely to increase the suspended solids.

In our experience, the first flush of storm water contains a very large quantity of suspended matter washed out of the sewers, and is organically very impure. This flush, moreover, usually occurs at the time when the rainfall flowing off the area causes the maximum flow in the sewer, the consequence being that an ordinary storm-overflow on the sewers often has the effect of diverting to a water-course the worst part of the storm-water, while allowing the less foul storm sewage which arrives later to pass to the tanks or filters.

289. As a general rule, the difficulty of dealing with storm-water lies, not so much in the actual quantity flowing off an area as the result of rain, as in the rate at which it flows off. This is, of course, much more marked at some places than at others, the flow-off of rain-water being much more rapid when the greater part of the drainage area is more or less impervious, where the district is hilly, or where the sewers are laid upon a steep gradient. For instance:—

At Calverley—population 2,300—where the district is hilly, the main sewer steep, the sewerage system combined, and with rock immediately underlying the soil, as the result of a rainfall of 0·46″ falling in five showers on June 9th, 1902, the flow of sewage showed five sudden rises bringing the rates of flow up to 13, 32, 26, 29 and 30 times the mean dry weather flow. The total flow of sewage for the day, however, was only increased from the mean dry weather flow of 12,000 gallons to 43,700 gallons, or 3·64 times.

If a storm overflow had been set at Calverley to come into operation when the rate of flow was six times the mean dry weather flow, a large quantity of storm-water would have been discharged, untreated, on this day; whereas if a reserve empty tank, with a holding capacity of about 12,000 gallons, had been provided, and the overflow had been from this tank, the whole of the sewage and storm-water would have been treated; the beds receiving 3·64 times the normal quantity of sewage.

This is not an unusual occurrence at Calverley, and it has, moreover, been often observed there and at other places that the storm sewage is usually most foul when the storm flow is at its maximum rate.

On the other hand, if the district is flat, and especially if there is much leakage of subsoil water into the sewers, the flow of sewage will increase less rapidly as the result of rain, but continue swollen for some hours, or possibly some days. Halton, Oswestry, and Newton-le-Willows may be cited as illustrations.

290. In our opinion, the difficulties of dealing with the increase in flow, due to storms, can best be met by the provision of stand-by tanks to receive the storm sewage in excess of that which can be passed through the ordinary tanks. The main overflow at the works should be from the stand-by tanks, and not from the outfall sewer, so that no sewage may escape without some settlement.

The stand-by tanks should, of course, be kept empty as far as possible, so as to be at once available when a storm comes on.

We have not sufficient experience to enable us to suggest by what rules the capacity of the stand-by tanks should be determined, but we should think that tanks capable of holding a †quarter (six hours' flow) of the mean daily dry weather flow would usually be sufficient.

Local circumstances would, however, have to be considered in settling the capacity required for any particular place.

291. As illustrating the effect of stand-by tanks of the capacity suggested, we may give some figures taken from the report of Mr. Baldwin Latham, to which we have already referred.

At Friern Barnet sewage works, during nineteen wet days (average rainfall at the sewage works, 0·281″ per day), in August, September and October, 1887, instead of a total dry weather flow of sewage of 232,009 cubic feet, 515,793 cubic feet were found to arrive, 283,784 cubic feet being therefore due to rain. Of the total (515,793 cubic feet), 125,679 cubic feet, or 24·37 per cent., arrived at a rate in excess of three times the mean dry weather flow; 89,558 cubic feet, or 17·36 per cent., in excess of four times the mean dry weather flow; 67,412 cubic feet, or 13·07 per cent., in excess of five times the mean dry weather flow, and 50,015 cubic feet, or 9·7 per cent., in excess of six times the mean dry weather flow.

Assuming that all sewage up to three times the mean dry weather flow had been taken through the ordinary precipitation tanks, and that all flows in excess of this were directed into stand-by tanks of capacity 3,050 cubic feet (the dry weather flow at Friern Barnet was 12,211 cubic feet per day), then, out of a total of 515,793 cubic feet, 390,114 cubic feet (75·6 per cent.) would have been filtered in the ordinary way, and 125,679 cubic feet, or 24·37 per cent., would have received, before discharge into the water-course, the settlement shown in the following table:—

† Stand-by tanks are, we believe, giving excellent results at Colne, Lancashire, and also at Chorley. We understand the stand-by capacity at Colne is equal to about one-half the daily dry weather flow, and at Chorley to about one-third of the dry weather flow.

Date.	Number of hours the flow exceeded 3 times the mean dry weather flow (which was 12,211 cubic feet per day).	Volume of sewage in excess of 3 times the mean dry weather flow.	Settlement given in stand-by tanks.
1887. - - -		Cubic feet.	
Aug. 16 - - -	5 hours	9,588	1 to 6 hours' continuous flow settlement after filling.
„ 17 - - -	1 hour	634	Quiescent settlement.
„ 20 - - -	1 hour	118	Quiescent settlement.
„ 26 - - -	3 hours	3,485	Mostly quiescent settlement.
„ 28 - -	2 hours	1,243	Quiescent settlement.
„ 29 - - -	1 hour	1,492	Quiescent settlement.
„ 30 - - -	10 hours	16,620	1 to 6 hours' continuous flow settlement.
„ 31 - - -	8 hours	32,554	1 to 6 hours' continuous flow settlement.
Sept. 1 - - -	12 hours	11,909	1 to 6 hours' continuous flow settlement.
„ 2 - - -	3 hours	1,150	Quiescent settlement.
„ 3 - - -	6 hours	4,583	Quiescent settlement
„ 4 - - -	1 hour	118	Quiescent settlement.
„ 6 - - -	3 hours	6,341	1 to 6 hours' continuous flow settlement.
„ 7 - - -	9 hours	5,238	1 to 6 hours' continuous flow settlement.
„ 16 - -	4 hours	5,246	1 to 6 hours' continuous flow settlement.
„ 17 - -	9 hours	17,431	1 to 6 hours' continuous flow settlement
„ 26 -	3 hours	2,246	Quiescent settlement.
„ 30 - - -	3 hours	1,175	Quiescent settlement.
Oct. 10 - - -	5 hours	4,506	1 to 6 hours' continuous flow settlement.

The results obtained by Mr. Baldwin Latham at Croydon throughout the years 1860 to 1886 show that in a total number of 139 days upon which heavy rain fell (average rainfall per day 0·488″), out of a total of 73,768,896 cubic feet of sewage and rain-water flowing in the sewer, 12,201,773 cubic feet (or 16·2 per cent.) arrived at a rate in excess of three times the mean dry weather flow.

Taking the dry weather flow at Croydon to be 321,000 cubic feet, stand-by tanks of the capacity suggested would, in this case, have held 80,000 cubic feet, and, if the whole of the sewage and storm-water up to three times the dry weather flow had been passed through the ordinary tanks and plant, then 16·2 per cent. (12,201,773 cubic feet) of the total flow would have been sent into the stand-by tanks. Of the 139 wet days during the period stated, the total flow in excess of three times the dry weather flow only exceeded 80,000 cubic feet, or the assumed capacity of the stand-by tanks, on fifty-two days. In this case, of the total flow of 12,201,773 cubic feet, in excess of three times the dry weather flow, 7,696,935 cubic feet would have received quiescent settlement in the stand-by tanks and 4,504,838 cubic feet from one to six hours' continuous flow settlement, before discharge into the water course.

Mr. Latham's gaugings of the South Norwood sewage flow show that on fourteen wet days between January 13th and August 11th, 1866 (average rainfall per day 0·35″), out of a total flow of sewage and storm-water of 1,617,594 cubic feet, of which not less than 1,268,217 cubic feet were due to rain, 881,453 cubic feet (or 54·49 per cent.) arrived at a rate in excess of three times the dry weather flow.

In this case, the provision of stand-by tanks of the capacity suggested (six hours' flow) would have given quiescent settlement to 59,083 cubic feet out of the total flow of 881,453 cubic feet in excess of three times the dry weather flow, and one to six hours' continuous flow settlement to 822,370 cubic feet before discharge into the water-course.

It is to be observed from Mr. Baldwin Latham's report "that there were no storm-overflows in connection with the South Norwood sewers at the time the gaugings were made, and that, the district being of a more or less impermeable character, the volume of rain entering the sewers is very considerable, having regard to the extent of the district and the population draining to the sewers."

We are greatly indebted to Mr. Baldwin Latham for the Report which he kindly made to us on the subject of the increase in the flow of sewers caused by storms. This Report is published in Appendix V.

Storm Water Filters.

292. Speaking generally, we are not in favour of special storm-water filters, for although, if well constructed and scientifically managed (*e.g.*, as at Manchester), they can be made to give good results, our experience has led us to the conclusion that—as generally constructed and used—they do not effect a purification in proportion to their cost.

If storm-water filters are not regularly used, their oxidising efficiency may, in times of dry weather, become impaired. If, therefore, they are to be used in dry weather, in order that they may be kept mature, it appears to us that they should be as well and as carefully constructed as the ordinary filters. It seems also false economy to have some part of the filtering area out of use for any length of time when the additional area, if used, would be of advantage in giving regular periods of rest to sections of the normal filtering area.

Amount to be filtered.

293. We think it may be taken that it is practicable to filter three times the mean dry weather flow, and while there are few or no data to show that this is the right amount for which filtration is required, we doubt whether, as a general rule, the filtration of any larger amount will be found to be necessary to prevent nuisance.

Assuming, that three times the dry weather flow had to be filtered, we consider that it would only be necessary to provide at a works 1½ times the area of filter which would be necessary if only the dry weather flow had to be treated; this area would, in our opinion, allow of the filtration of three times the mean dry weather flow, as the filters can be worked at an increased rate during storms.

Recommendation.

(a) *Overflows on Branch Sewers.*

294. It is probably impracticable to dispense altogether with storm overflows on branch sewers, but in our opinion these should be used sparingly, and should usually be set so as not to come into operation until the flow in the branch sewer is several times the maximum normal dry weather flow in the sewer.

No general rule can be laid down as to the increase in flow which should occur in the branch sewers before sewage is allowed to pass away by the overflow untreated. The Rivers Board, or in districts where there is no Rivers Board, the County Council, should have power to require the local authority to alter any storm overflows which, in their opinion, permit of an excessive amount of unpurified sewage to flow over them. The local authority should have the right to appeal to the Central Authority in any case in which they consider that the requirement of the Rivers Board is unreasonable or impracticable of fulfilment.

The general principle should be to prevent such an amount of unpurified sewage from passing over the overflow as would cause nuisance.

(b) *Treatment of Storm Water Sewage at the Works.*

295. The usual requirements of the Local Government Board in regard to the treatment of storm sewage are that any increase in flow up to three times the normal dry weather rate should be fully dealt with by the ordinary complete plant, and that a certain number of additional dilutions—up to a total of six—should be treated on special storm filters. These requirements should, we think, be modified: they are, in our opinion, not sufficiently elastic; and, moreover, experience has shown that special storm filters, which are kept as stand-by filters, are not efficient. We find that the injury done to rivers by the discharge into them of large volumes of storm sewage chiefly arises from the excessive amount of suspended solids which such sewage contains, and that these solids can be very rapidly removed by settlement. We therefore recommend, as a general rule—

(1) That special stand-by tanks (two or more), should be provided at the works and kept empty for the purpose of receiving the excess of storm water which cannot properly be passed through the ordinary tanks. As regards the amount which may be properly passed through the ordinary tanks, our experience shows that in storm times the rate of flow through these tanks may usually be increased up to about three times the normal dry weather rate without serious disadvantage;

(2) That any overflow at the works should only be made from these special tanks, and that this overflow should be arranged so that it will not come into operation until the tanks are full;

(3) That no special storm filters should be provided, but that the ordinary filters should be enlarged to the extent necessary to provide for the filtration of the whole of the sewage, which, according to the circumstances of the particular place, requires treatment by filters.

(4) As regards the overflow from the outfall sewer to the stand-by tanks, the size of the stand-by tanks, the amount of storm sewage which should be filtered, and the arrangements generally for dealing with storm sewage at the outfall works, the Rivers Board, or the County Council in areas in which no Rivers Boards have been established, should have similar power to that which we have proposed in regard to overflows on branch sewers, and the Local Authority should have a similar right of appeal to the Central Authority.

SEPARATE AND COMBINED SYSTEMS OF SEWERS.

296. In recent years there has been a tendency to favour the adoption of separate sewers to carry what is called surface water, and some local authorities have obtained, by means of local acts, special powers enabling them to call upon frontagers in private streets to lay down two sewers instead of one.

In the Public Health Bill of last session (1907) a clause, dealing with this subject, was originally included, but it was omitted during the passage of the Bill through Parliament.

In our opinion the cases in which the provision of a separate system can properly be justified are rare, and it appears to us that the relative merits of the separate and combined systems have not always been sufficiently considered.

It is obvious that the provision of two systems of sewers and two sets of house drains would very largely increase the initial outlay on drainage works, the exact amount of the increase depending on local circumstances.

It seems generally to have been assumed by advocates of the separate system that the liquid brought down by surface water sewers is sufficiently pure to need no purification, and further, that by excluding this water from the ordinary sewers a much smaller area of land or filters, as the case may be, will suffice for the purification of the sewage.

Neither of these assumptions is altogether justified.

297. As regards the quality of the liquids which are discharged from surface-water sewers, we may refer to the following analyses which we have made:—

Chemical Analyses.

No. of Sample.	Rugby. 231	Aldershot Camp. 311	Aldershot Camp. 314	South Norwood. 174	South Norwood. 179	South Norwood. 182	South Norwood. 187A
	Street washings taken from a surface water drain. Street very clean from heavy showers.	Street washings from surface ditch.	Street washings.	Street water. Incubated before analysis.	Surface street water. Incubated before analysis.	Street washings after running 2 hours.	Street water after 0·04″ rain.
	Monday, March 4th, 1901, 10 a.m.	Tuesday, July 2nd, 1901, 12.45 noon.	Wednesday July 3rd, 1901, 11.45 a.m.	Wednesday November 14th, 1900, 2.15 p.m.	Wednesday November 21st, 1900, 1.0 p.m.	Wednesday November 28th, 1900, 12.45 noon.	Saturday, December 1st, 1900, 11.15 a.m.
Ammoniacal Nitrogen	0·09	0·49	1·70	0·19	1·25	0·47	0·52
Albuminoid Nitrogen	0·10	0·49	0·34	0·06	0·14	0·42	0·08
Total Organic Nitrogen	0·23	1·05	0·64	—	—	0·65	—
Nitrous Nitrogen	0·01	trace.	0·0	0·24	—	trace.	0·10
Nitric Nitrogen	0·05	0·12	0·02			0·42	
Oxygen absorbed *at once*	0·66	2·76	0·81	0·39	—	2·76	0·23
Oxygen absorbed *in* 4 *hours*	1·83	8·93	3·46	—	—	9·79	—
Incubator test	Sweet.	Black Sulphides.	Black Sulphides.	No smell.	Putrid black Sulphides.	Strongly putrid.	Clean.
Suspended solids by Centrifuge (vols.)	91·0	Too gritty.	65	—	—	—	—
	Not much traffic on this street. The sample was brown and turbid, with a large amount of gritty sediment.	Turbid and brown, but the liquid had only a slight brown tinge when filtered. Much sand and also brownish suspended matter. Clean smell.	Turbid and brown. Considerable suspended matter with grit at bottom of bottle. Very slight putrid smell.	Liquid had a slight brown tinge. Much sand. Very pure (chemically).	No smell.	Very turbid. Filtered liquid brown but fairly clear. Much grit. No smell.	Dark coloured flocculent sediment.

Bacteriological Analyses.

Description of Sample.	Total number of Bacteria per c.c. Gelatine at 20°C.	Total number of Bacteria per c.c. Agar at 37°C.	Number of B. Coli (or closely allied forms per c.c.).	Number of Spores of B. Enteritidis sporogenes per c.c.
96A. Rugby. Street water from separate system. June 20/00.*	15,900,000	94,000	10,000 (Indol + ·0001 c.c.) + ·01, – ·001 c.c. "gas" in gelatine shake culture.	+ ·1, – ·01 c.c. At least 10 but less than 100.
231. Rugby. Street "Washings." March 4/01.§	930,000	12,400	1,000 (Indol + ·001 c.c.) Negative result with ·1 c.c. "gas" in gelatine shake culture. + ·01, – ·001 c.c. Neutral red broth test. + ·01, – ·001 c.c. Litmus milk test.	+ ·01, – ·001 c.c. At least 100 but less than 1,000.
311. Aldershot Camp. Street "Washings." July 2/01.	7,500,000	640,000	+ ·0001, – ·00001 c.c. Neutral red broth test. + ·001, – ·0001 c.c. Litmus milk test. + ·001, – ·0001 c.c. "gas" in gelatine shake cultures.	+ ·1, – ·01 c.c. At least 10 but less than 100.
314. Aldershot Camp. Street "Washings." July 3/01.	22,800,000	900,000	+ ·00001 c.c. Neutral red broth test. + ·0001, – ·00001 c.c. Litmus milk test. + ·001, – ·0001 c.c. "gas" in gelatine shake cultures.	+ ·01, – ·001 c.c. At least 100 but less than 1,000.
174. S. Norwood. Brook (represents street "Washings"). 14/11/00.	1,470,000	88,000	At least 10 (Indol + ·1 c.c.). + ·1, – ·01 c.c. "gas" in gelatine shake cultures.	+ ·01, – ·001 c.c. At least 100 but less than 1,000.
179. S. Norwood. Surface water from streets. 21/11/00.	3,840,000	293 000	10,000 not 100,000 (Indol + ·00001 c.c.). + ·01 c.c. "gas" in gelatine shake cultures.	+ ·1, – ·01 c.c. At least 10 but less than 100.
182. S. Norwood. Street water after running 2 hours. 28/11/00.	13,700,000	154,000	10,000 (Indol + ·0001 c.c.).	+ ·01, – ·001 c.c. At least 100 but less than 1,000.
188B. S. Norwood. Street "Washings" after running 4 hours. 1/12/00.†	9,900,000	380,000	1,000 (Indol + ·001 c.c.) + ·1, – ·01 c.c. "gas" in gelatine shake cultures.	+ ·01, – ·001 c.c. At least 100 but less than 1,000.

* Two guinea-pigs (a and b) were subcutaneously inoculated with 1 c.c. (a) and 2 c.c. (b) of sample 96A (street washings). Both showed a strong local reaction; (a) guinea-pig recovered, but (b) guinea-pig suffered from ulceration of the abdominal wall and died on the fourth day.

† Two guinea-pigs (a, b) were subcutaneously inoculated with 1 c.c. (a) and 2 c.c. (b) of sample 188B; (a) guinea-pig developed a big swelling at the site of the inoculation, but eventually recovered completely; (b) guinea-pig died on the second day.

§ A guinea pig was subcutaneously inoculated with 4 c.c. of sample 231 (street washings). It died on the second day, doubtless from the effects of the injection.

The chemical analyses of these samples may be shortly summarised as follows :—

No. 231, street "washings" taken from a surface-water drain at Rugby on March 4th, 1901, at a time when the street was very clean after heavy showers, was turbid and brown with a large amount of gritty sediment, but comparatively pure as regards organic matter; it withstood incubation.

No. 311, street "washings" from a surface-water ditch at Aldershot, was drawn on the 2nd July, 1901, after two days' heavy rainfall; at the time of drawing, the water in this ditch was flowing at about the rate of ten million gallons per 24 hours. The above sample was brown and turbid (though it had only a slight brown tinge when filtered), and it contained a great deal of sand and also brownish suspended matter. The analyses gave the high figure of 0·49 parts Albuminoid Nitrogen, 1·05 Total Organic Nitrogen, and 8·93 "Oxygen absorbed" in four hours. Though this had a clean smell when analysed, it became black and putrid on incubation.

No. 314, street "washings" and roof water from Aldershot Camp, drawn July 3rd, 1901, after three days' rain, was muddy from a considerable quantity of suspended solids with grit in addition. Though the aggregate organic matter was less than in sample No. 311 (the figures being 0·34 Albuminoid Nitrogen, 0·64 Total Organic Nitrogen, and 3·46 "Oxygen absorbed"), it was smelling slightly when analysed and became black and putrid on incubation.

No. 174, drawn November 14th, 1900, was a sample of surface water from streets and front roofs drawn at South Norwood during sharp showers, the weather having been showery on the day previous. It contained a good deal of sand, but was comparatively pure as regards organic matter and kept good upon incubation.

No. 179, drawn November 21st, 1900, was another sample of surface water from the South Norwood streets, after moderate showers, the streets having been previously washed fairly clean by rain. This did not contain much sediment, but was organically more impure than the preceding sample; it had no smell when received, but became putrid upon incubation.

No. 182 was drawn on November 28th, 1900, at South Norwood, after the surface drain had been running for three hours. It was very turbid and brown and contained much grit. Organically, it might be classed as a dilute sewage.

No. 187a, South Norwood street water, drawn December 1st, 1900, after a slight rainfall, was comparatively pure as regards organic matter. Though it showed a good deal of flocculent sediment, it kept sweet upon incubation.

Three out of these seven samples were therefore non-putrescible; but the other four were undoubtedly polluting liquids.

Bacteriologically, all the samples may be classed as bad.

Although the above samples were few in number, they show (1) that even when a street water is comparatively pure organically, it requires settlement for grit (Nos. 174 and 231); and (2) that even after long-continued rain, street surface waters may be very impure (Nos. 182, 311 and 314).

298. The witnesses who have given evidence on this question have agreed that the first flush of water from a surface-water system during a storm is of such a foul nature that it ought to be purified, if practicable, especially if the system brings water from paved open spaces such as markets, squares, etc.

Messrs. G. H. Pickles and Raymond Ross gave the following analysis of a typical sample of surface water from a surface-water drain at Burnley, taken during the early period of a storm :—

	Parts per 100,000.
Free Ammonia	·8
Albuminoid Ammonia	·2
Chlorine	4·0
Oxygen absorbed	5·3
Total solids	71·2
Suspended matter	44·0

They stated, also, that this sample contained about 800,000 bacteria per c.c. as shown by gelatine plate cultivation at 23°C.

Mr. Bolton, in his evidence relating to Heywood, gives the following analysis of a sample of road water, taken in the principal streets during the first rushes of storm surface water :— 21096.

	Parts per 100,000.
Ammoniacal Nitrogen	1·11
Albuminoid Nitrogen	·49
Oxygen absorbed in 3 minutes	12·5
Oxygen absorbed in 4 hours	19·9
Chlorine	8·7
Solids in suspension	84 { vol. 25, non vol. 59
Solids in solution	73 { vol. 22, non vol. 51
Total solids	157

299. Experience also shews that with two sets of drains to each house there is danger of the sewage drain being connected with the surface-water sewer, and in densely populated areas, slops and other filthy liquids are often emptied into street gullies, and pass directly into the surface-water sewer.

There can be no doubt, therefore, that the liquid brought down by surface-water sewers is frequently of a polluting nature, and that, in many cases, it might be necessary to provide for its treatment.

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300. As to the other assumption, that by keeping surface water out of the sewers the area of filters or land necessary for purification may be materially reduced, we may refer to the experiments which we carried out at Accrington, in regard to the filtration of diluted and undiluted septic tank liquor (see pages 16 and 110 *et seq.*).

These experiments shewed that, within ordinary limits of concentration and volumes treated, the amount and nature of the organic impurity present mainly determine, in practice, the ease or difficulty of purification; in other words, that, within limits, mere dilution does not affect the size of the filtering plant which is necessary. Of course, if the dilution is so great as to cause water-logging of the filters, their purifying power would be seriously diminished, and this statement would not hold good.

We may also observe that the flushing of sewers by rain water, which occurs with the combined system, is in itself useful, and that there is some evidence to show that filters work better when storm sewage, from which the solids have been settled, is occasionally passed through them.

24260, Fowler. 22745, Watson. 24955, Wilkinson.

301. As regards the cases in which the adoption of a separate system for surface water may be allowed, we may refer to the evidence of Dr. Fowler, Mr. Watson, and Mr. Wilkinson. These gentlemen have had considerable experience, and they expressed the view that in large towns the separate system is impracticable, that in urban districts a combined system is justified on sanitary and economical grounds, and that only in villages, country districts, and suburban areas, where there is little traffic and where the surface water will not be very foul, may the separate system sometimes be adopted with advantage.

With these views we generally concur, and we think it would be unwise to confer on all local authorities power to enforce the adoption of the separate system of sewerage, and the provision of two sets of drains in every house.

In our opinion this power should not be conferred on any local authority until the local circumstances have been carefully considered by some independent tribunal.

Recommendation.

302. We recommend that in any case in which a local authority wishes to adopt the separate system of drainage for the whole or any part of their district, they should be required to apply to the Central Authority, and that the Central Authority should be empowered to confer on the local authority, by order, such powers as may be deemed necessary.

As regards the powers which may be necessary, we may observe that the provisions which are generally contained in local Acts in regard to this matter seem to be defective. If separate sewers are provided, the local authority should have a clear power to enforce the provision of separate drains, but the local Acts to which our attention has been drawn do not modify the powers of the local authority under the general law in regard to bye-laws as to the drainage of houses.

Moreover, the powers of the local authority in this connection should not necessarily be limited to new streets and new houses.

As a general rule, the expense of altering existing drains should fall on the local authority, and there may be some instances in which it would be equitable that they should bear some portion of the additional cost even in the case of drains being constructed for the first time.

The Central Authority should therefore have power to include in their Order such provisions for the allocation of the cost as they consider equitable, having regard to the local circumstances.

PART VI.—STANDARDS FOR SEWAGE EFFLUENTS.

303. A number of chemists and others were kind enough to furnish us with their views on the question of standards, in response to a circular letter which we issued in May, 1903. This letter and the replies are printed in Appendix VII.

We have also examined several witnesses on this subject, and have ourselves made some experimental investigations.

The harm caused by allowing unpurified, or imperfectly purified, sewage to flow into rivers and streams may be placed under one or more of the following headings:—The de-aeration of the water of the river, and consequent injury to fish; the putrefaction of organic matter in the river to such an extent as to cause nuisance; the production of sewage fungus and other objectionable growths; the deposition of suspended matter, and its accumulation in the river bed or behind weirs; the discharge into the river of substances, in solution or suspension, which are poisonous to fish or to live stock drinking from the stream; the discoloration of the river; and the discharge into the river of micro-organisms of intestinal derivation, some of which are of a kind liable, under certain circumstances, to give rise to disease.

304. We observe that previous Commissions have reported that, of all the processes which were proposed for the purification of sewage, or of water polluted by excrementitious matter, there is not one which is sufficiently effective to warrant the use, for dietetic purposes, of water which has been so contaminated, and the 1868 Commission stated that, in their opinion, "rivers which had received sewage, even if that sewage had been purified before its discharge, were not safe sources of potable water." We, therefore, conclude that the framers of the Rivers Pollution Prevention Act, 1876, did not contemplate that local authorities should be required so to deal with their sewage that the rivers into which the purified sewage flowed might be regarded as safe sources of water supply, in cases in which the water was not to be filtered before distribution.

305. In our opinion much the same position must be taken up to-day. Although the methods available for the purification of sewage are more numerous than when the 1868 Commission reported, our examination of a very large number of effluents from sewage farms, and from artificial filters of various kinds, shows that, although such effluents may be very good as judged by chemical and physical tests, they are generally liable to contain large numbers of micro-organisms of intestinal derivation, and that if such organisms are to be destroyed, or eliminated, the effluents must be subjected to some treatment additional to that which is ordinarily employed.

We have carried out some experiments for the purpose of ascertaining the practicability of certain of the methods which have been suggested for the removal or destruction of these micro-organisms. These experiments, which are described in Dr. Houston's Report, Appendix IV., have shown that, while it would be practicable to render sewage effluents fairly pure, bacteriologically, the cost of the necessary additional treatment would be serious.

306. Moreover, a false sense of security would be obtained by the adoption of such further treatment unless, at the same time, storm overflows on sewers were abolished.

In the great majority of towns, sewers are provided with storm overflows, by which, in times of storm, large quantities of sewage are discharged into the river or stream untreated. Such discharges, we find, are frequently more impure, bacteriologically, than the normal crude sewage.

In the opinion of some engineering witnesses whom we have called before us, it would generally be impracticable to dispense with storm overflows, but assuming, as an engineering possibility, that they could generally be dispensed with, it is quite clear that the necessary enlargement of the sewers would involve a very large outlay. In some towns, if there were no storm overflows, the effect of a storm would be to cause the flow in the sewers to be very many times the normal rate for a short period.

307. By constructing a separate system of sewers for storm water the effect of storms on the other sewers would no doubt be greatly lessened, but if bacterial purity is to be required in the case of all discharges from sewers, it would be necessary to provide a second plant for the treatment of the liquids flowing in the storm water sewers, as these liquids are often exceedingly impure.

The amount of liquid which would be brought down by such separate sewers would vary, according to local conditions, but during the course of a year it would probably be at least half as much as the volume carried by the other set of sewers.

308. In our opinion, the cost of reconstructing the sewers so as to allow of the abolition of storm overflows, together with the cost of providing and maintaining purification plant which could be relied on at all times to render the total refuse waters of a town both chemically and bacteriologically pure, would in most cases be practically prohibitive; and further, even if this additional burden were placed on local authorities, the water of rivers would generally still require to be treated before it could be safely distributed for drinking purposes.

309. We are satisfied that rivers generally, those traversing agricultural as well as those draining manufacturing or urban areas, are necessarily exposed to other pollutions besides sewage, and it appears to us, therefore, that any authority taking water from such rivers for the purpose of water supply must be held to be aware of the risks to which the water is exposed, and that it should be regarded as part of the duty of that authority, systematically and thoroughly, to purify the water before distributing it to their customers.

310. Apart from the question of drinking waters, we find no evidence to show that the mere presence of organisms of a noxious character in a river constitutes a danger to public health or destroys the amenities of the river. Generally speaking, therefore, we do not consider that in the present state of knowledge, we should be justified in recommending that it should be the duty of a local authority to treat its sewage so that it should be bacteriologically pure.

311. The evidence adduced before us and the results of our own investigations show that the extent to which the purification of a sewage need be carried in order that none of the other injuries mentioned in paragraph 303 shall be done to the river into which it is discharged varies with the particular circumstances of the town and river concerned.

The statute law, however, recognises no graduated standards of purity for sewage effluents.

Under the Rivers Pollution Prevention Act, 1876, in the case of sewage entering non-tidal waters, the duty is imposed on the local authority of adopting the best practical and available means to render the sewage harmless before it enters the river, and no local circumstances may be taken into account. The effluent by itself is alone to be considered.

312. We fully realise that from the point of view of administration it is simpler to regard the effluent alone, and also that it has not been usual for County Councils, Rivers Boards, or others, to press the provisions of the Act of 1876 unduly. Our terms of reference require us, however, to have regard to the "*economical* and efficient" discharge of the duties of local authorities, and in view of the importance of not requiring a local authority to incur any further expenditure on sewage disposal than the circumstances of its area require, we feel strongly that the law should be altered so as to allow local circumstances to be taken into account.

Suspended Solids in Effluents.

313. One point in regard to which we think that strict regulations will usually be found necessary is the reduction of the suspended solids of an effluent to a low figure, before that effluent is allowed to escape into a watercourse. As is well known, these suspended

solids are always—or practically always—putrescible. Indeed, we cannot recall any instance in our own experience in which such solids, when examined apart from the liquid portion of the effluent, were non-putrescible.

Our observations show that the volatile matter of the suspended solids in effluents from artificial filtration may be taken, on a rough average, as constituting about two-thirds of the whole, the remaining one-third being mineral matter. Although it is not strictly correct to say that this "volatile" matter is all organic, we think that it may be considered so for practical purposes.

A description, by Messrs. O'Shaughnessy and Kinnersley, of the suspended solids washed out in the effluent from one of the Birmingham percolating filters is to be found in the *Journal of the Society of Chemical Industry* for 1906. They found them to consist of a very complex mixture of structureless matter, dead organisms undergoing disintegration, zooglea, mineral matter, etc.

A large number of specific instances are given, in the *reports on the various sewage works which have been under observation for the Commission, of the rates at which such solids take up dissolved oxygen from water.

The results show that the suspended solids from biological sewage filters, whether contact beds or percolating filters, are in themselves putrescible, and that they are capable of taking up oxygen from water comparatively rapidly. So long as such solids are kept moving in oxygenated water, or in water containing nitrate in solution, they will not give rise to nuisance from smell, but if allowed to accumulate in the sluggish reaches of a stream, they will ultimately form black and putrid mud, which will draw upon the oxygen in the supernatant water; if present in very large quantity, they will, in those circumstances, give rise to objectionable conditions.

314. Our own experience, and also the evidence which we have received, leads us to attach much importance to the prevention of a large amount of suspended solids being discharged into most rivers and streams, and our observations show that it is quite practicable to produce effluents fairly free from suspended solids.

The following places, among others, where various systems of treatment are followed, may be cited as giving a general effluent containing at most 3 parts of suspended matter per 100,000:—

Birmingham.	Friern Barnet.	Royton.
Burnley.	Guildford.	Salford.
Carshalton.	Hampton.	Salisbury.
Caterham.	Hendon.	Staines.
Chesterfield.	Heywood.	St. Albans.
Chorley.	Kingston.	Shipley.
Clifton.	Newcastle-under-Lyme.	Wednesbury.
Darwen.	Oswestry.	Withington.
Dorking.	Prestolee.	Withnell.
Exeter	Radcliffe.	

As a general rule, we consider that the harm due to suspended solids would not be serious, if the effluents contained not more than 3 parts of suspended solids† per 100,000, and it is shown by experience that this would not be an unreasonable figure to demand in the majority of cases. There are, of course, cases where a larger quantity of solids might be safely allowed in an effluent, while in some others even 3 parts might be too much.

Other Qualities of Effluents.

315. We shall discuss in the next section of this report various tests for sewage effluents, but we may at once state that we doubt whether the figures obtained in the laboratory have, in the past, been sufficiently considered in connection with observed conditions of the stream to justify positive inferences being drawn from such figures as to the effect of effluents on streams.

* See Appendix III. † This is equivalent, as a rule, to about 2 parts of organic matter in suspension.

In connection with an investigation which we are making in regard to the disposal of distillery waste liquids, we have constructed a number of artificial streams. We find that effluents which are derived from strong original liquids may often contain large amounts of organic matter in solution, and yet not take up dissolved oxygen rapidly from water, or cause injury to streams into which they are discharged. If these observations had not been made such effluents, judged by the empirical tests in common use, might have been regarded as polluting liquids.

These observations, together with other experiments and the work done by others, show that the effect of an effluent on a stream does not generally depend on the absolute amount of organic matter contained in it, but rather on the nature and condition of that organic matter, and that the important thing to ascertain in examining an effluent, is the extent to which the original organic matter has undergone fermentation.

We are extending this method of observation to a variety of streams and effluents, and in our final report we hope to be able to indicate, by reference to figures obtained in the laboratory, a range of standards of varying degrees of stringency.

Recommendation.

316. We recommend that the Central Authority should determine the nature of the tests which are to be applied for the purpose of standards, and that it should be made the duty of the Rivers Board, or of the County Council, in areas not under the jurisdiction of a Rivers Board, to determine from time to time, subject to appeal to the Central Authority, what standards should be adopted.

317. In the first instance it would be convenient that the Central Authority should prescribe one standard for all non-tidal waters, in place of the existing statutory provisions. It would then rest with the Rivers Board or County Council to fix, subject to appeal to the Central Authority, a higher or lower standard, in any case in which they were of opinion that the circumstances required or justified a different standard.

318. We further recommend that no action should be allowed to be brought in respect of damage alleged to be due to the discharge of an effluent which complies with the standard fixed for the water into which it is discharged, but that in such cases complaint should be made to the Central Authority, and, if a *prima facie* case is made out, that Authority should ascertain whether the complaint is well founded and should be empowered to fix a different standard if the circumstances are shown to require it.

In cases where it is alleged that the effluent does not comply with the statutory standard, and that damage is caused by the discharge of such effluent, action should be brought in the ordinary courts.

But any questions arising as to whether the effluent complies with the statutory standard or as to whether the damage has been caused by the discharge of the effluent in respect of which complaint is made, should be referred by the Court to the Central Authority for determination. The costs of such determination should be borne by the parties to the action in such proportions as the Court may determine.

319. Power should be conferred on the Central Authority to suspend from time to time the operation of any standard, to allow time for the construction of works, or for any other reason which, in their opinion, justified such suspension.

TESTS FOR SEWAGE EFFLUENTS IN RELATION TO STANDARDS.

320. The experiments which we have already made show that the mere estimation of the amount of organic matter in an effluent does not, by itself, afford a sufficiently reliable index as to the effect which that effluent will have on any stream into which it may be discharged.

Effluents which are derived from strong sewages may contain comparatively large amounts of organic matters, and yet not take up oxygen rapidly from water or cause any serious growth of sewage fungi in streams, while effluents derived from weak sewages, although containing smaller amounts of organic matters, may take up oxygen comparatively rapidly and foul a stream into which they are discharged.

The primary object of applying tests to a sewage effluent should be to ascertain whether the effluent may be discharged into a stream without giving rise to effects such as these, and we are extending our observations on streams with a view to ascertaining the value of various tests from this point of view.

Until these observations are completed we do not propose to report finally on the question of tests and standards. We can, however, at once state that any figures of analysis, unless they bear a direct relation to the state of the effluent as regards fermentative change, may be misleading.

321. According to our present knowledge, an effluent can best be judged by ascertaining, first, the amount of suspended solids which it contains, and, second, the rate at which the effluent, after the removal of the suspended solids, takes up oxygen from water.

In applying this test it is important that the suspended solids should be removed, and estimated separately.

Small variations in the amount of suspended solids in effluents may seriously affect the rate at which the effluents take up oxygen, and unless these solids are first removed, the dissolved oxygen absorption test might give a misleading figure as to the character of the effluent.

322. For the guidance of local authorities we may provisionally state that an effluent would generally be satisfactory if it complied with the following conditions :—

(1) That it should not contain more than 3 parts per 100,000 of suspended matter; and

(2) That, after being filtered through filter paper, it should not absorb more than:

(*a*) 0·5 part by weight per 100,000 of dissolved or atmospheric oxygen in 24 hours;

(*b*) 1·0 part by weight per 100,000 of dissolved or atmospheric oxygen in 48 hours; or

(*c*) 1·5 parts by weight per 100,000 of dissolved or atmospheric oxygen in 5 days.

At many sewage works which we have had under observation effluents of this class are uniformly produced.

As regards the carrying out of the dissolved oxygen test, or aeration test as it is sometimes called, we may refer to page 15 of this Report, which deals with the test in relation to sewage, and also to pages 96 and 438 of Appendix VI.

Growths in Streams.

323. The question of growths in streams is one of some importance and difficulty.

Even the best effluents contain a certain amount of plant food in solution and therefore tend to promote vegetable growths. In the case of a stream receiving well purified and nitrated effluents, these growths are green. If, however, green growths form in quan-

tity, and become detached and washed down into stagnant pools, they must ultimately undergo decomposition and may possibly give rise to nuisance.

This aspect of the question is being further studied; but we may remark that it does not seem practicable to purify sewage thoroughly without the production of nitrates which remain in the effluent, and tend to promote growths.

In the case of a stream receiving imperfectly purified effluents, grey growths (leptomitus, sphaerotilus, etc.) may be fostered. These not only give a stream an unpleasant appearance, and tend to choke its bed, but when washed down and allowed to accumulate, may become very offensive, especially in warm weather. So far as our observations have gone, such growths flourish best in a mixture consisting partly of unpurified sewage liquor and partly of oxygenated and nitrated water or effluent.

This is illustrated by some channel experiments at Chorley, which we began towards the end of February, 1907. One of the channels carried a mixture of 75 volumes of filter effluent and 25 volumes of well-clarified precipitation tank liquor. The mixture gave the following average figures of analysis:—

Parts per 100,000.	Average.	Number of Estimations.
Ammoniacal nitrogen (1·34 to 3·6)	2·2	4
Albuminoid nitrogen (0·14 to 0·20)	0·16	3
Oxidized nitrogen (1·76 to 2·32)	2·2	3
"Oxygen absorbed" in 4 hours (0·81 to 2·21)	1·4	6
Dissolved oxygen taken up from water *in 5 to 8 days* (0·65 to 2·81)	1·4	6
Dissolved oxygen taken up from water *in 24 hours* (0·18 to 1·16)	0·8	3
Incubator test (by smell)	All passed.	6

In spite of these comparatively good figures, and the fact of the liquid being non-putrescent upon incubation, the channel was, in June, 1907, filled from end to end with a thick grey fungoid growth.

Another channel, conveying purified filter effluent, had only a green growth, coated to some extent with effluent solids, while a third channel which carried filter effluent plus a proportion of storm water equivalent, *on the average*, to 30 per cent. of the total volume of liquid delivered to the channel, became full of black putrescent mud, but had little or no sewage fungus.

We are not at present in a position to state with certainty, by reference to figures of analysis, what effluents will, and what effluents will not, cause objectionable growths in streams.

Nitrates in Effluents.

324. Although a well nitrated effluent usually takes up dissolved oxygen from water slowly, this is not always the case. The following effluent (from a strongly ammoniacal sewage) is an instance of this variation:—

	Parts per 100,000.
Ammoniacal nitrogen	13·02
Albuminoid nitrogen	0·48
Nitrous nitrogen	0·26
Nitric nitrogen	4·70
Solids in suspension	Trace.
"Oxygen absorbed" at 27° C. (80° F.) *at once*	1·96
"Oxygen absorbed" at 27° C. (80° F.) in 4 hours	5·62
Dissolved oxygen taken up from water at 18°C. (65°F.)	
(*a*) in 24 hours	0·89
(*b*) in 48 hours	2·16
Incubator test (by smell)	Passed.

Here, although there are about five parts of oxidised nitrogen present in the liquid, there still remains a considerable quantity of readily oxidizable organic matter. Conversely, instances might be given of effluents, poor in nitrate, which took up very little dissolved oxygen from water.

Chemical Poisons in Effluents.

325. We have not yet studied this point in much detail, but we think that very few effluents in which the organic matter had been well oxidized, would contain chemical poisons in quantity sufficient to do harm to fish life, and that the heavy metals would be brought down in the sludge. When the Leeds sewage was known to contain a considerable quantity of arsenic, the effluents from its biological filtration showed only minute traces of it.

Cases may occur where chlorine compounds, acids, or alkalies, might be present in an effluent. We have heard, for instance, of the addition of lime, for the purpose of temporarily sterilizing a poor effluent; such effluents would of course be detrimental to fish.

The Relation of certain Tests to One Another

326. Dr. McGowan has made a careful comparison of the figures of analysis of 163 effluents of varying degrees of purity and obtained by various artificial processes. In most of the cases a determination was made of the dissolved oxygen taken up by the effluent from water in twenty-four hours, as well as of the "oxygen absorbed" from permanganate, etc.

As a result of this comparison we find that:—

(1) The figures for albuminoid nitrogen and for "oxygen absorbed" from (strong) permanganate in four hours show a close parallelism, but bear no constant ratio to one another. In well, or fairly well, purified effluents, comparatively free from suspended solids, the ratio will usually be something like one part of albuminoid nitrogen to ten parts of "oxygen absorbed" in four hours at 27° C. (80° F.).

(2) The ratio of albuminoid to total organic nitrogen in an effluent is usually from 1 : 2 to 1 : 3, though it may in certain cases be either below or above those figures. When an effluent contains a large quantity of suspended solids, the ratio tends to be high.

(3) There is nothing like a definite ratio between the figures for albuminoid (or total organic) nitrogen and ammoniacal nitrogen in an effluent. The actual quantity of free ammonia left in an effluent, especially if it be compared with that in the original sewage or tank liquor, furnishes, however, a very valuable indication of the extent to which oxidation has been promoted by the filter.

(4) The ratio of "oxygen absorbed" at once from (strong) permanganate to "oxygen absorbed" in four hours is usually fairly constant at about 1 : 3 to 1 : 4, though there are a good many exceptions.

The main object of the test—"oxygen absorbed" at once (or in three minutes)—is to show whether there is an abnormal quantity of quickly oxidisable matter, whether organic or inorganic, in a sewage liquid. It cannot be regarded as a substitute for the four hours test.

(5) The ratio of dissolved oxygen taken up from water in twenty-four hours at 18° C. (65° F.) to "oxygen absorbed" from permanganate in four hours at 27° C. (80° F.) shows very wide variations, and the figures cannot be said to bear much relation to one another, except in a very general way. When the ratio is low, the effluent is more often than not of poor quality. With a high ratio —say, over 1 : 5—the effluent is almost always a good one.

(6) The ratio of dissolved oxygen taken up in *twenty-four hours* to "oxygen absorbed" from permanganate *at once* varies very much also; as a general rule the better effluents show the higher ratios.

The Relation between the Incubator or Non-putrescibility Test and the taking up of Dissolved Oxygen from Water.

327. There is no certain correspondence between the results of these two tests. An artificial effluent, made by adding excess of nitrate to a diluted sewage, takes up dissolved oxygen at a rapid rate, but the nitrate prevents it from putrefying upon incubation.

At the same time we find that when an effluent is pretty well purified, there is fairly definite relationship between the two tests.

Of the 163 effluents of varying degrees of purity which were examined by Dr. McGowan, 107 did not putrefy on incubation; forty-nine putrified; and seven were doubtful.

Of the 107 effluents which did not putrefy on incubation, ninety-eight were tested for dissolved oxygen absorption, and were found to take up an average of 0·57 part per 100,000 in 24 hours. The figures ranged from 0·0 to 3·2 parts per 100,000, and in most of the cases where a high figure was obtained, there was much suspended solid in the effluent. There were thirty-five effluents which contained over 3 parts of suspended solids per 100,000 (the average being 7·1 parts), and these took up an average of 0·85 part of dissolved oxygen in 24 hours. The remaining sixty-three effluents, which contained 3 parts or less of suspended solids per 100,000, took up an average of 0·41 parts of dissolved oxygen. Again, of nineteen of the effluents which did not putrefy on incubation, but which seemed of somewhat indifferent quality as judged by the figures of analysis, only five took up more than 1 part of dissolved oxygen.

Of the forty-nine effluents which putrefied on incubation, thirty-three were tested for dissolved oxygen absorption, and were found to take up from 0·57 to 7·0 parts (or an average of 2·3 parts) of oxygen from water in 24 hours.

We may summarise the position as follows:—

(1) It is very rare indeed for an effluent which (apart from suspended solids) takes up little dissolved oxygen from water to fail upon incubation.

(2) It is comparatively infrequent for an effluent (apart from suspended solids) which withstands incubation to take up dissolved oxygen from water at a rapid rate.

(3) In the great majority of cases an effluent which fails to withstand the incubator test will also take up much dissolved oxygen from water; and

(4) An effluent which takes up much dissolved oxygen from water will also usually fail upon incubation.

Both these tests depend upon the fermentative changes which may take place in an effluent, on keeping, but a standard based upon a low figure of dissolved oxygen absorption would, in some cases, be more stringent than a standard of non-putrescibility alone.

328. It is, we think, probable that an effluent which does not take up dissolved oxygen from the water of a stream more rapidly than that water can naturally re-aerate itself from the air, would neither give rise to unpleasantness nor—assuming the absence of chemical poisons—injure fish life, but this is a point on which we shall be able to speak more definitely after the conclusion of our observations on streams.

* *Condition of Effluent as regards Aeration.*

329. In some circumstances the question of the amount of dissolved oxygen contained in the effluent would be of importance. If the effluent were almost completely de-aerated, as many contact bed effluents are, and were to be discharged into a stream, the volume of which was small as compared with the volume of effluent, the mere admixture of stream and effluent would, at all events near the point of discharge, produce a liquid in which the amount of dissolved oxygen would be far below the saturation point.

It should be added that it would probably not be difficult to aerate a contact bed effluent previous to its discharge into the stream.

Effluents from percolating filters are usually well aerated.

* See also Report by Dr. Letts and Dr. Adeney. Appendix VI.

PART VII.—POLLUTION OF ESTUARIES AND TIDAL WATERS.

330. In our fourth report we dealt with the question of the pollution of tidal waters, with special reference to contamination of shell-fish.

As regards the standard of effluent that can be permitted for tidal waters, having regard to the reasonable protection of salmon fisheries and the avoidance of nuisance, we stated that we did not think it practicable to lay down any fixed rules, as the necessities of each case would depend on a variety of considerations. We were, however, of opinion that in certain circumstances sewage should be purified before it is discharged into tidal waters.

We therefore proposed that the Rivers Board should be empowered, subject to appeal to the Central Authority, to call upon a local authority to adopt some method of purification in cases where purification was necessary.

331. Professor Letts and Dr. Adeney kindly agreed to collect and collate the results of investigations bearing on the question of standards for tidal waters, as regards offensive putrefaction, and injury to fish, and they have presented to us a report on this subject which is contained in Appendix VI.

Their report contains the results of much original work as well as the results, which they have brought together, of the work done by other observers.

Professor Letts and Dr. Adeney have devoted a large amount of time to the work, and we are greatly indebted to them for their report, which is a document of considerable value.

The report affords further proof that any provisions which may be enacted for dealing with the pollution of tidal waters must be of an elastic character.

As an appendix to the report, Dr. Gilbert Fowler has supplied a memorandum as to the results of some observations which he made as to the discharge of septic tank sludge into an estuary near Ipswich.

PART VIII.—SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS.

(I) PREVIOUS REPORTS.

INTERIM REPORT. CD. 685 [1901].

332. Our first Report was of an interim character and contained the following conclusions :—

(1) No land is entirely useless for purification of sewage, "but in the case of stiff clay and peat lands "the power to purify sewage seems to depend on the depth of the top soil."

"There are, of course, numerous gradations in the depths of top soil which are met with in nature, and "it is not easy to draw the line between lands which contain a sufficient depth to justify their use, and lands "which do not."

"We are, however, forced to conclude that peat and stiff clay lands are generally unsuitable for the "purification of sewage, that their use for this purpose is always attended with difficulty, and that where "the depth of top soil is very small, say 6 inches or less, the area of such lands which would be required "for efficient purification would in certain cases be so great as to render land treatment impracticable."

(2) ". . . we are satisfied that it is practicable to produce by artificial processes alone either from sewage, "or from certain mixtures of sewage and trade refuse, such, for example, as are met with at Leeds and Man-"chester, effluents which will not putrefy, which would be classed as good according to ordinary chemical "standards, and which might be discharged into a stream without fear of creating a nuisance."

"We think, therefore, that there are cases in which the Local Government Board would be justified "in modifying, under proper safeguards, the present rule as regards the application of sewage to land."

(3) ". . . as a result of a large number of examinations of effluents from sewage farms and from artificial "processes we find that while in the case of effluents from land of a kind suitable for the purification of sewage "there are fewer micro-organisms than in the effluents from most artificial processes, yet both classes of "effluents usually contain large numbers of organisms, many of which appear to be of intestinal derivation, "and some of which are of a kind liable, under certain circumstances at least, to give rise to disease."

"We are of opinion, therefore, that such effluents must be regarded as potentially dangerous, and we "are considering whether means are available and practicable for eliminating or destroying such organisms, "or, at least, those giving rise to infectious diseases."

(4) "It is of the utmost importance that the simplest possible means should be provided for adequately "protecting all our rivers," . . . and "it will be desirable, probably for some time to come, that scientific "experiments should be carried on in order to ascertain all the real dangers of pollution, against which they "should be protected."

"In the present state of knowledge, and especially of bacteriology, it is difficult to estimate these dangers "with any accuracy, and it seems quite possible that they should be either exaggerated or under-valued "according to the pre-disposition of those who have to deal with them. An authority, guided by medical "considerations, might not unnaturally be inclined to insist on a degree of purity which may ultimately "prove in certain cases to be uncalled for, while another authority, with its mind fixed upon economy, "might shrink from taking essential precautions."

. . . "the general protection of our rivers is a matter of such grave concern as to demand the "creation of a separate Commission, or a new department of the Local Government Board, which shall be "a Supreme Rivers Authority, dealing with matters relating to rivers and their purification, and which, "when appeal is made to them, shall have power to take action in cases where the local authorities have "failed to do so."

SECOND REPORT. CD. 1178 [1902].

333. Our second Report was a formal document covering certain scientific papers which were presented as an appendix to that Report.

THIRD REPORT. CD. 1486 [1903].

334. In our third Report we dealt with the relations between local authorities and manufacturers in regard to the disposal of manufacturing effluents. We found that the present state of the law was most unsatisfactory, that the attitude of local authorities towards manufacturers had differed widely, and that many manufacturers were seriously handicapped. Our investigations showed that purification of trade effluents by the local authority is in the great majority of cases practicable; purification by the manufacturer is in some cases difficult, if not impracticable; while purification by the manufacturer would generally be more costly than purification by the local authority.

It also appeared that the local authorities, as well as the manufacturers, were of opinion that there should be laid on the local authority a distinct obligation to receive trade effluents.

335. Our recommendations on this point were as follows :—

"We are, therefore, of opinion that the law should be altered so as to make it the duty of the local "authority to provide such sewers as are necessary to carry trade effluents as well as domestic sewage, and "that the manufacturer should be given the right, subject to the observance of certain safeguards, to dis-"charge trade effluents into the sewers of the local authority if he wishes to do so."

"We do not think it possible to provide, by direct enactment, what these safeguards should be. In "each district it would probably be desirable that the local authority should frame regulations which should "be subject to confirmation by a Central Auuthority. In most cases, however, these regulations could provide "definite standards for the different manufacturers as regards preliminary treatment, and it appears from "the evidence that manufacturers would much prefer to have standards to work to."

"Power to vary the standards or to dispense with them altogether in special cases would be necessary."

"Although the duty of receiving trade effluents should, we think, be imposed on the local authority, "cases may arise in which they should be wholly or partially relieved of it."

"For example, we find that in some instances the effluent discharged from the manufactory is of a com-"posite character, the greater part of which might with advantage be easily dealt with by the manufacturer "if it were kept separate. In such cases we think the manufacturer would generally be willing to adopt "this course, but provision is necessary for those cases in which the local authority and manufacturer could "not agree."

"Further, although we have received no conclusive evidence to show that there are trade effluents which "could not be purified by the local authority, we do not deny the possibility of such cases arising."

"And it is possible that in some cases, as, for example, of a large manufactory being newly established in "a small district, it might be necessary to relieve the authority of the obligation to treat the trade effluent "or to enable them to exact some special contribution from the manufacturer, not only for the cost of treat-"ment, but also towards capital expenditure."

"It is obvious, therefore, that some tribunal will be required for settling differences between the local "authority and the manufacturer, and for relieving the local authority in exceptional cases, either wholly "or partially, of their obligation to provide sewers and disposal works of sufficient capacity for trade effluents "as well as ordinary sewage."

"We are of opinion that generally no special charge should be made on the manufacturer in those cases "in which the regulations as to preliminary treatment are complied with."

"As we have already stated, it is desirable that, wherever practicable, some preliminary treatment "should be carried out by the manufacturer."

"But where the manufacturer is unable to comply with these regulations we consider that the local "authority should be empowered to make a special charge."

"Power should also be granted to make a special charge, even when preliminary treatment is adopted, "where there are exceptional circumstances as regards volume, quality or otherwise."

Settlement of Differences Between Local Authorities and Manufacturers.

336. The chief questions upon which we considered that differences might arise were :—

(1) The refusal of a local authority to allow a particular trade effluent to enter their sewers.

(2) The refusal of a local authority to construct or enlarge sewers for the purpose of a particular manufactory.

(3) The question of varying general regulations as to preliminary treatment by the manufacturer.

(4) The amount of the special charge to be imposed on the manufacturer.

(5) The removal of sludge.

The balance of opinion we found to be strongly in favour of the view that for the settlement of these questions it is necessary to constitute a Central Board possessing adequate technical knowledge, such as the Supreme Rivers Authority which we recommended in our Interim Report.

As regards this matter we reported as follows :—

"We have been struck by the large sums which have been expended in appeals to Courts, but apart "from the question of expense we are strongly of opinion that the ordinary Courts are not suitable for the "determination of these questions, and we venture to think that the judgment of the Master of the Rolls "in the case of Attorney-General v. Whitmore, to which we have already referred, clearly supports this view. "His comment that 'the evidence was very complicated, the expert witnesses who were called not only giving "evidence quite inconsistent with one another, but some of them giving evidence in cross-examination, which "was quite inconsistent with what they said in examination in chief,' might apply to many similar cases."

"The scientific questions to be solved would in most instances be capable of actual determination by "a properly-equipped Central Authority, and there can be little doubt that such direct proof would be far "less costly than the process of endeavouring to arrive at the truth through the evidence of expert witnesses "in a Court of Law."

"Moreover, the matters to be determined include, not only scientific questions on which witnesses may "be expected to differ, but also considerations of an administrative character which should more properly "be dealt with by a Government Department."

"Further, we find that a Central Authority possessing adequate technical knowledge, would command "the confidence of local authorities and manufacturers."

"In our opinion a properly equipped central authority is essential, and we unhesitatingly recommend "the creation of such an authority."

"In the interests of river purification as well as of the trade of the country we consider it is of the highest "importance that the changes in the law which we have recommended should be made. But these changes "would not in our opinion, be of much use apart from the creation of a Central Authority for the determination "of differences between the local authority and the manufacturer."

"If the settlement of these differences be left to the ordinary Courts, differential treatment of manu-"facturers, with all the objections to it, will be certain to continue."

We also recommended that, for the due protection of rivers, River Boards should be formed for other parts of the country, similar to the three which already exist in Lancashire and Yorkshire, and that these boards should be empowered to determine, subject to appeal to the Central Authority, certain of the differences between local authorities and manufacturers.

We further advised that it should be the duty of Rivers Boards to inspect public water supplies and to report to the Central Authority any cases of dangerous pollution of such supplies which they may detect; and that the Central Authority should be empowered, after due inquiry, to order the purveyors of the water to adopt such means as, in the opinion of the Central Authority, were reasonable and necessary for removing or diminishing the danger.

We also recommended that the Central Authority might, with the aid of the Rivers Boards, very properly collect such information as is available throughout the country in regard to waste of water by pumping from mines, and in regard to the abstraction of water from one district, for the supply of another district, to the detriment of the water supply of the district from which the water was taken. We consider that the collection of such information should precede the consideration of the question whether legislative interference in regard to these matters is desirable.

FOURTH REPORT. CD. 1883 [1904].

337. In our fourth Report, we dealt with the pollution of tidal waters, with special reference to the contamination of shell-fish. We stated that:—

"After carefully considering the whole of the evidence on this point, we are satisfied that a considerable "number of cases of enteric fever and other illness are caused by the consumption of shell-fish which have "been exposed to sewage contamination; but in the present state of knowledge, we do not think it possible "to make an accurate numerical statement, at any rate as regards the whole country."

"There can, however, be no doubt that the evil is sufficiently grave to demand a remedy."

Our main recommendation for dealing with the evil was stated in the following terms:—

"After carefully considering the whole of the evidence, together with the results of our own investiga-"tions and local inquiries, we are strongly of opinion that the only way in which this evil can be effectively "dealt with is by placing tidal waters under the jurisdiction of a competent authority, and conferring on "that authority power to prevent the taking of shell-fish for human consumption from any position in which "they are liable to risk of dangerous contamination, and to enforce restrictions as regards pollution, and "as regards waters, foreshores, pits, ponds, beds and layings in which shell-fish are fattened or stored, as and "when required."

"For this purpose the powers of the authority must be elastic. The case of each river and estuary is a "problem by itself, and it would not be practicable to fix by enactment any standard or standards which would "be generally suitable to the widely different conditions of different cases. Moreover, as the conditions are "shifting in character, it is necessary to provide some permanent machinery by which restrictions can be "varied."

After considering various alternative suggestions as to the Controlling Authority, we stated that:—

"We entirely agree with the view which has been pressed upon us by a large number of witnesses that "Rivers Boards would be the most suitable bodies in whom to vest the local control which we are now dis-"cussing. Their control over inland waters is of a similar character to the control which is required over "tidal waters (estuarial and other), and it is desirable and fitting that their jurisdiction should be extended "to tidal waters for public health purposes. There are indeed no other local bodies possessing the "necessary qualifications, and the only practicable alternative to giving them jurisdiction would seem to "be to place the whole control in the hands of a Central Department."

We recommended therefore:—

"That the necessary power of control over the pollution of tidal waters, and over waters, foreshores, "pits, ponds, beds, and layings where shell-fish are grown, fattened or stored, should be vested in the Rivers "Boards, subject to appeal to a central authority."

In the Report we set forth, in detail, the procedure which the Rivers Boards and Central Authority should follow. We also dealt with the question of the means which should be adopted for avoiding danger from the consumption of foreign shell-fish.

As regards other evils, besides the contamination of shell-fish, which had to be guarded against in the case of discharge of sewage into tidal waters, we made recommendations dealing with these matters.

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS.

(2) PRESENT REPORT.

GENERAL CONCLUSION.

338. It is practicable to purify the sewage of towns to any degree required, either by land treatment or by artificial filters, and there is no essential difference between the two processes. Page 9.

The main questions, therefore, to be considered in the case of a town proposing to adopt a system of sewage purification are, first, what degree of purification is required in the circumstances of that town, and of the river or stream into which its liquid refuse is to be discharged; and, secondly, how the degree of purification required can, in the particular case, be most economically obtained.

Removal of Suspended Matters.

We find that it is generally desirable to remove from the sewage, by a preliminary process, a considerable proportion of the grit and suspended matters, before attempting to purify the sewage on land or filters. Page 18.

Sedimentation Tanks.

339. *Quiescent Sedimentation.*—Two to three hours quiescence is usually sufficient to produce a tank liquor fairly free from suspended solids, but owing to the fact that some sewages contain a larger proportion than others of solids that settle very slowly, no general rule can be laid down as to the necessary period of quiescence. With this form of treatment the deposit in the tanks should be frequently removed. Page 19.

Continuous Flow Sedimentation.—The amount of settlement effected does not depend alone upon the period of flow, but upon a number of other factors. If the tank liquor is to be treated upon filters of fine material, the period of flow should generally be from 10 to 15 hours. The tanks should be cleaned out at least once a week. Page 20

Septic Tanks.

340. All the organic solids present in sewage are not digested by septic tanks, the actual amount of digestion varying with the character of the sewage, the size of the tanks relative to the volume treated, and the frequency of cleansing. With a domestic sewage, and tanks worked at a 24-hours rate, the digestion is about 25 per cent. Page 21.

The liquor issuing from septic tanks is bacteriologically almost as impure as the sewage entering the tanks. Page 22

Domestic sewage which has been passed through a septic tank is not more easily oxidised in its passage through filters than domestic sewage which has been subjected to chemical precipitation or simple sedimentation. Page 22.

Page 25. No definite rules can be laid down as to how long a septic tank should be run without cleaning. In the case of small sewage works (serving populations of say 100 to 10,000 persons), the tanks should generally be allowed to run, without cleaning, so long as the suspended matter in the tank liquor shows no signs of affecting the filters injuriously. For larger works it would generally be advisable to run off small quantities of sludge at short intervals of time.

Page 26. The rate of flow through a septic tank is a matter in which the needs of each place require special consideration, but at few places should the sewage be allowed to take longer than 24 or less than 12 hours to flow through the tank. In no case should less than two tanks be provided, and they should be arranged so that, if necessary, one tank can be used alone.

Page 28. As regards digestion of sludge and quality of tank liquor, a closed tank possesses no advantages over an open tank. There is less risk of nuisance if the tank and the feed channels to the filters are covered in.

Page 29. By passing septic tank liquor through tanks of a size sufficient to hold about one quarter of the day's flow, with the addition of from 2 to 3 grains of lime per gallon to the liquor, the suspended solids in the liquor are materially reduced, a considerably larger quantity of the liquor can be treated per cube yard of filter, and the offensive character of the liquor is largely destroyed.

Chemical Precipitation.

Page 30. 341. In the case of sewages which contain certain trade waste, and strong sewages from water-closet towns, it is generally desirable to subject the sewage to some form of chemical treatment before attempting to oxidise the organic matter contained in it. In most cases careful chemical precipitation materially aids the deposition of the suspended solids, and facilitates subsequent filtration.

Page 30. No general rule can be stated with regard to the capacity of precipitation tanks. With continuous flow, an eight hours rate is usually sufficient to produce a fairly good tank liquor from a domestic sewage of average strength.

Page 30 If sewage is allowed to remain quiescent in the tank, two hours settlement would usually suffice.

Relative Cost of Different Tank Treatments.

Page 43. 342. In the absence of special circumstances favouring a particular plan, it would appear that there is very little difference in annual cost between the various methods of tank treatment when taken in conjunction with the cost of subsequent filtration through percolating filters, assuming that the kind of filter adopted in each case is that which is best adapted to the particular tank treatment provided.

Filters.

Page 52. 343. Within ordinary limits, the depth of a contact bed makes, practically, no difference to its efficiency per cube yard.

Page 53. We think that it would be generally inadvisable to construct contact beds of a greater depth than 6 feet or of a less depth than 2 feet 6 inches.

Page 87. For practical purposes and assuming good distribution, the same purification will be obtained from a given quantity of *coarse* material, whether it is arranged in the form of a deep or of a shallow percolating filter, if the volume of sewage liquor treated per cube yard be the same in each case.

Page 87. With regard to percolating filters of *fine* material, if the liquid to be purified were absolutely free from suspended and colloidal solids, and if thorough aeration could be maintained, the statement just made for filters of coarse material might possibly hold good for filters of fine material also. In practice, however, these conditions can scarcely be maintained with large rates of flow, and we think that the greatest efficiency can be got out of a given quantity of *fine* material by arranging it in the form of a shallow filter rather than of a deep filter. But we are not in a position to make an exact quantitative statement as to the difference in efficiency of the two forms.

344. The amount of sewage which can be purified per cube yard of contact bed or of percolating filter varies—within practical limits—nearly inversely as the strength of the liquor treated. This statement is based on the assumption that the size of the material of which the filter is composed is, in each case, suitable to the character of the liquor treated, and that the material is arranged at the proper depth to secure maximum efficiency. Page 119.

Detailed particulars as to the amounts which can be treated per cube yard of filter are given on page 117.

Taking into account the gradual loss of capacity of contact beds, a cubic yard of material arranged in the form of a percolating filter will generally treat about twice as much tank liquor as a cubic yard of material in a contact bed. Page 119

In the case of sewage containing substances which have an inhibitory effect upon the activity of micro-organisms, the working power per cube yard of filter of either type may be more nearly equal. This point, however, is not clearly established. Page 119.

Percolating filters are better adapted to variations of flow than contact beds. Page 119.

Effluents from percolating filters are usually much better aerated than effluents from contact beds, and, apart from suspended solids, are of a more uniform character. On emptying a contact bed, the first flush is usually much more impure than the average effluent from the bed. Page 119.

The risk of nuisance from smell is greater with percolating filters than with contact beds. Page 119.

With percolating filters there is apt to be nuisance from flies, especially with filters constructed of coarse filtering material. In the warmer months of the year, such filters swarm with members of the *Psychodidae*, which, though appearing to breed and develop in the filters, may usually be seen in large numbers on the walls of houses, or buildings close to or on the works. Page 119

Treatment of Sewage on Land.

345. There is no essential distinction between effluents from land and effluents from artificially constructed filters. Pages 137 and 142.

Effluents from those soils which are particularly well adapted for the purification of sewage contain only a very small quantity of unoxidised organic matter, and are usually of a higher class than effluents from artificial filters as at present constructed and used. Page 142.

Effluents from soils which are not well adapted for the purification of sewage may often be very impure. Page 142.

Sludging of Mill Dams.

346. In any case in which the Rivers Board should be of opinion that the sludging of a mill dam by turning the accumulated sludge into the stream would give rise to a nuisance, and that it would be financially practicable for the mill owner to adopt some other method of cleansing the dam, the Rivers Board should be empowered, by notice, to direct the mill owner not to turn the sludge into the stream. Page 191.

It should be provided that any mill owner deeming himself aggrieved by such a direction, might, within some fixed period, appeal to the Central Authority. The decision of the Central Authority should be final.

Should any cases arise, in which it is important that the sludge should not be turned into the stream, but in which the Rivers Board are of opinion that the cost of adopting any other method of cleansing the dam would be prohibitive to the millowner, we recommend that the Rivers Board should be empowered to represent the case to the Central Authority, and that the Central Authority should be empowered, after due enquiry, to direct that the sludge shall not be turned into the stream. If the Central

Authority should be satisfied that the cost of adopting some other method of cleansing the dam would be greater than the millowner could be reasonably called upon to bear, they should be empowered to direct that a portion of the cost should be borne by the local authorities whose districts would be benefited.

Effect of Trade Effluents on Sewage Purification.

age 192.

347. All the trade effluents of which we have had experience interfere with or retard processes of purification to some extent, but we are not aware of any case where the admixture of trade refuse makes it impracticable to purify the sewage upon land or by means of artificial processes, although in certain extreme cases special processes of preliminary treatment may be necessary.

Nuisance from Smell.

Page 195.

348. All sewage works are liable, at times, to give off unpleasant smells; they should, therefore, be situated away from dwelling houses, wherever this is practicable.

The nuisance is apt to be considerably greater where the sewage contains brewery refuse in any quantity; but, on the other hand, the presence of some trade effluents, such, *e.g.*, as iron salts or tarry matters, tends to render the process of purification less offensive.

The extent of the risk of nuisance depends, however, not only on the character of the sewage, but also on the method of treatment adopted.

General Observations bearing on Choice of a Method of Sewage Treatment.

Page 202.

349. The selection of a method of sewage disposal should depend primarily on local conditions.

If a sufficient quantity of good land, to which the sewage can gravitate, can be purchased for about £100 an acre, land treatment would usually be the cheapest method to adopt.

In cases where only clay land is available, it would generally be cheaper and more satisfactory to provide artificial filters.

Page 202.

350. Given conditions favourable to each process, there is little difference as regards cost between any of the different forms of tank treatment when these are considered along with the cost of subsequent filtration.

Page 202.

Single contact will, generally, only yield a good effluent where the sewage to be treated is weak, and then only after good preliminary treatment. For the purification of partially settled weak sewage, and for well, as also for partially, settled sewage of average strength, if the case is one in which a good effluent is required, double contact is necessary, while if a strong sewage has to be treated, triple contact is necessary, unless the preliminary treatment is exceptionally good.

Page 203.

In nearly every case a greater rate of filtration per cube yard can be adopted if the material is arranged in the form of a percolating filter, than if it is used in contact beds. In many cases the rate of filtration through percolating filters may be double or nearly double what it could be with contact beds.

Pages 67 & 203.

Where the liquor to be treated contains much suspended matter, it is usually advisable to construct filters, whether contact or percolating, with coarse filtering material. Where the preliminary treatment has effectively removed the greater part of the suspended matter, it is best to use fine material in the filters.

Storm Overflows on Branch Sewers.

Page 209

351. Storm overflows on branch sewers should be used sparingly, and should usually be set so as not to come into operation until the flow in the branch sewer is several times the maximum normal dry weather flow in the sewer. No general rule can be laid down as to the increase in flow which should occur in the branch sewers before sewage is allowed

to pass away by the overflow untreated. The Rivers Board, or in districts where there is no Rivers Board, the County Council, should have power to require the local authority to alter any storm-overflows which, in their opinion, permit of an excessive amount of unpurified sewage to flow over them. The local authority should have the right to appeal to the Central Authority in any case in which they consider that the requirement of the Rivers Board is unreasonable or impracticable of fulfilment.

The general principle should be to prevent such an amount of unpurified sewage from passing over the overflow as would cause nuisance.

Treatment of Storm Water Sewage at the Works.

352. As a general rule, special stand-by tanks (two or more) should be provided at the works, and kept empty for the purpose of receiving the excess of storm water which cannot properly be passed through the ordinary tanks. As regards the amount which may be properly passed through the ordinary tanks, our experience shows that in storm times the rate of flow through these tanks may usually be increased to about three times the normal dry weather rate without serious disadvantage. Page 210.

The overflow at the works should be made from these special tanks, and should be arranged so that it will not come into operation until the tanks are full.

Special filters which are only used in times of storm are not usually efficient, and should not be provided.

Any extra quantity of sewage arriving at the works in storms, which has to be filtered, should be treated on the ordinary filters, which should be made sufficiently large for the purpose.

As regards the size of the stand-by tanks, the amount of storm water sewage to be filtered, and the arrangements generally for dealing with the storm sewage at the outfall works, the Rivers Board or the County Council in areas in which no Rivers Boards have been established, should have similar power to that which we have proposed in regard to overflows on branch sewers, and the local authority should have a similar right of appeal to the Central Authority.

In most cases it will probably suffice to provide stand-by tanks capable of holding one quarter of the daily dry weather flow, and it will not be necessary to provide for *filtering* more than three times the normal dry weather flow.

Under the arrangements which we recommend no storm sewage arriving at the outfall works would be discharged without some settlement.

Separate Systems of Sewers.

353. In any case in which a local authority wishes to adopt the separate system of drainage for the whole or any part of their district, they should apply to the Central Authority, and that Authority should be empowered to confer on the local authority, by order, such powers as are required. Page 21(

As regards the powers that are required, the provisions which are generally contained in local Acts in respect of this matter seem to be defective. If separate sewers are provided, the local authority should have a clear power to enforce the provision of separate drains, but the local Acts to which our attention has been drawn do not modify the powers of the local authority under the general law in regard to bye-laws as to the drainage of houses. Moreover, the powers of the local authority should not necessarily be limited to new streets and new houses.

As a general rule, the expense of altering existing drains should fall on the local authority, and there may be some instances in which it would be equitable that they should bear some portion of the additional cost even in the case of new roads.

The Central Authority should, therefore, have power to include in their Order such provisions for the allocation of the cost as they consider equitable, having regard to the local circumstances.

Standards for Sewage Effluents.

Page 218.

354. Our terms of reference require us to have regard to the "*economical* and efficient" discharge of the duties of local authorities, and in view of the importance of not requiring a local authority to incur any further expenditure on sewage disposal than the circumstances of its area require, we feel strongly that the law should be altered so as to allow local circumstances to be taken into account.

Page 220.

We recommend that the Central Authority should determine the nature of the tests which are to be applied for the purpose of standards, and that it should be made the duty of the Rivers Board, or of the County Council in areas not under the jurisdiction of a Rivers Board, to determine, from time to time, subject to appeal to the Central Authority, what standards should be adopted.

In the first instance it would be convenient that the Central Authority should prescribe one standard for all non-tidal waters, in place of the existing statutory provisions. It would then rest with the Rivers Board or County Council to fix, subject to appeal to the Central Authority, a higher or lower standard in any case in which they were of opinion that the circumstances required or justified a different standard.

We further recommend that no action should be allowed to be brought in respect of damage alleged to be due to the discharge of an effluent which complies with the standard fixed for the water into which it is discharged, but that in such cases complaint should be made to the Central Authority, and, if a *prima facie* case is made out, that Authority should ascertain whether the complaint is well founded, and should be empowered to fix a different standard if the circumstances are shown to require it.

In cases where it is alleged that the effluent does not comply with the statutory standard, and that damage is caused by the discharge of such effluent, action should be brought in the ordinary Courts.

But any questions arising as to whether the effluent complies with the statutory standard, or as to whether the damage has been caused by the discharge of the effluent in respect of which complaint is made, should be referred by the Court to the Central Authority for determination. The costs of such determination should be borne by the parties to the action in such proportions as the Court may determine.

Power should be conferred on the Central Authority to suspend, from time to time, the operation of any standard, to allow time for the construction of works, or for any other reason which, in their opinion, justified such suspension.

Tests for Sewage Effluents in Relation to Standards.

Page 222.

355. According to our present knowledge, an effluent can best be judged by ascertaining, first, the amount of suspended solids which it contains, and, second, the rate at which the effluent, after the removal of the suspended solids, takes up oxygen from water.

In applying this test it is important that the suspended solids should be removed, and estimated separately.

For the guidance of local authorities we may provisionally state that an effluent would generally be satisfactory if it complied with the following conditions:—

(1) That it should not contain more than 3 parts per 100,000 of suspended matter; and

(2) That, after being filtered through filter paper, it should not absorb more than:

(*a*) 0·5 part by weight per 100,000 of dissolved or atmospheric oxygen in 24 hours.

(*b*) 1·0 part by weight per 100,000 of dissolved or atmospheric oxygen in 48 hours; or

(*c*) 1·5 parts by weight per 100,000 of dissolved or atmospheric oxygen in 5 days.

THE CENTRAL AUTHORITY.

356. To secure the economical and efficient discharge of the duties of local authorities, and others, in regard to pollution, and adequately to protect the public health and the amenities of rivers, the statutory provisions in regard to these matters must be of an elastic character.

The conditions of different cases vary to such an extent that the necessary control cannot, in our opinion, be provided by any direct enactment which could be enforced by the ordinary Courts.

Throughout our Reports, this fact has been fully recognised, and we have proposed, in regard to many matters, that ultimate control should be vested in an adequately equipped Central Administrative Authority, and that, as far as practicable, the local Rivers Board should, in accordance with regulations framed by the Central Department, act as a first tribunal.

Among the more important questions which have to be dealt with under the new conditions of administration which we are contemplating, are the following:—

(i.) Disputes between local authorities and manufacturers as to the terms and conditions on which trade effluents shall be admitted into sewers.

(ii.) The control of shell-fish layings so as to prevent the taking of shell-fish for human consumption from positions in which they are liable to risk of dangerous contamination.

(iii.) The protection of water supplies from pollution.

(iv.) The collection of information as to the water supplies available in various parts of the country.

(v.) The collection of information as to the need of water in various parts of the country.

(vi.) The settlement of standards for different reaches of water.

(vii.) Conferring powers on local authorities, in suitable cases, to provide separate systems of sewers for surface water and to enforce the provision of separate drains.

(viii.) The settlement of questions as to the extra amount of sewage which a local authority should be required to treat during storms.

There are also numerous questions in regard to the purification of polluting liquids which, in the interests of the public, have still to be worked out, and it is essential that the Central Authority should be properly equipped for undertaking such special investigations as they may from time to time find necessary, and for collecting and collating the work done by others.

Since the date of our appointment considerable developments have taken place in regard to the disposal of sewage, and there is every reason to think that further changes will occur in the future.

Unless the Central Department keep in close touch with all such changes, and from time to time report on them, it is not possible for local authorities throughout the country fully to utilise the results of valuable work which is being done at many places, and hence, to perform their duties in the most economical as well as efficient manner.

THE POSITION OF OUR INQUIRY.

357. In this Report we have dealt with the main question of what methods of sewage disposal may properly be adopted by local authorities. The remainder of our work will be chiefly concerned with the disposal of trade effluents when not mixed with sewage.

We have already investigated the disposal of distillery effluents, and shall issue a separate Report on this subject very shortly.

Concurrently with our investigation of the methods available for disposing of other trade effluents we shall continue our observations on the effect of discharging effluents of known composition into streams, with a view to reporting more fully on the question of standards and tests.

Page 188. We are continuing, for another season, the experiments on the manurial value of sewage sludge, and are also making some observations on a few other points.

IDDESLEIGH (*Chairman*),

T. WALTER HARDING,

WILLIAM RAMSAY,

W. H. POWER,

T. J. STAFFORD,

REGINALD A. TATTON.

F. J. WILLIS,

Secretary,

7th August, 1908.

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CLASS I.

Strong or Very Strong Sewage.

Typical Analysis of Sewage from a water-closet town with a water supply of 25 to 30 gallons a head. Separate system of sewers.

Ammoniacal nitrogen	9·0
Oxygen absorbed in 4 hours	17·0
Suspended solids	40·0

Strength 160 to 170.

Ammoniacal nitrogen.	Oxygen absorbed in 4 hours.	Suspended solids.
7·5	20	40

Strength 175 to 200.

Typical Analysis of Sewage from a slop-water town, having few water-closets, where the water supply is about 10 to 15 gallons a head, and where the sewers are only the partially separate system.

Ammoniacal nitrogen	6·0
Oxygen absorbed in 4 hours	25·0
Suspended solids	40·0

Strength 200 to 230.

Chemical precipitation and quiescent settlement for 2 hours.

Precipitation Liquor.

Ammoniacal nitrogen	7·0
Oxygen absorbed in 4 hours	8·0
Suspended solids	2 to 5

Strength 90.

Effluents.

	Double contact beds.	Percolating filters of coarse material (deep).	Percolating filters of fine material (shallow).	Good land (Filtration with little cropping).
Rate of filtration per cube yard.	65 galls. (2½ fillings)	150 galls.	100 galls.	25,000 to 30,000 galls. per acre per day. (5 to 6 galls. per sq. yd.).
Ammoniacal nitrogen	2·0	2·0	2·0 to 3·0	0·25
Nitric nitrogen	1·5	2·0	3·0	1·5
Oxygen absorbed in 4 hours	3·0	3·0	2·5	0·3 to 0·5
Suspended solids	2·0	4·0 to 5·0	2·0 to 3·0	Possible traces of growth, washed out from drains.

Variable effluents, sometimes putrescible.

Chemical precipitation and 8 hours' continuous flow settlement.

Precipitation Liquor.

Ammoniacal nitrogen	7·0 to [illegible]
Oxygen absorbed in 4 hours	9·[illegible]
Suspended solids	8[illegible]

Strength 95 to 100.

Effluents.

	Double contact beds.	Percolating filters of coarse material (deep.)	Percolating filters of medium material (shallow.)	Good land (Filtration with little cropping).
Rate of filtration per cube yard per day.	50 galls. (2 fillings)	100 galls.	75 galls.	25,000 galls. per acre (5 galls. per sq. yd.).
Ammoniacal nitrogen	2·0	2·5	2·5	0·25
Nitric nitrogen	1·5	2·0	2·0 to 3·0	1·5
Oxygen absorbed in 4 hours	3·0	3·0	2·5	0·3 to 0·5
Suspended solids	2·0	6·0	5·0	Possible traces of growth, washed out from drains.

Variable effluents, sometimes putrescible.

Quiescent settlement for 2 hours.

Settled Sewage.

Ammoniacal nitrogen	7·0 to 7·5
Oxygen absorbed in 4 hours	10·0
Suspended solids	10·0

Strength 100 to 105.

Effluents.

	Triple contact beds.	Percolating filters of coarse material (deep).	Percolating filters of fine material (deep).	Good land (Filtration with little cropping).
[illegible] of filtration per cube [illegible]d per day.	40 galls. (4 fillings)	75 galls.	35 galls.	20,000 galls. per acre per day (4 galls. per sq. yd.).
[illegible]oniacal nitrogen	1·0	1·0	0·5	0·25
[illegible] nitrogen	2·0 to 2·5	3·0	4·0	1·5
[illegible]en absorbed in 4 hours	1·5	3·0	2·5	0·3 to 0·5
[illegible]nded solids	Trace	6·0 to 8·0 and more.	5·0	Possible traces of growth, washed out from drains.

Fine material in tertiary beds. Rate of filtration could not be doubled in wet weather.

Continuous flow settlement for 15 hours.

Settled Sewage.

Ammoniacal nitrogen	7·0 to 7·5
Oxygen absorbed in 4 hours	12·0
Suspended solids	15 to 20

Strength 120.

Effluents.

	Triple contact beds.	Percolating filters of coarse material (deep).	Percolating filter of fine material (deep).	Good land (Filtration with little cropping).
Rate of filtration per cube yard per day	30 galls. (3 fillings).	50 galls.	25 galls.	20,000 galls. per acre per day (four galls. per sq. yd.).
Ammoniacal nitrogen	0·5	1·0	0·75	0·25
Nitric nitrogen	2·5 to 3·0	3·5	4·0	1·5
Oxygen absorbed in 4 hours	1·5	3·0 to 4·0	2·5 to 3·0	0·3 to 0·5
Suspended solids	Trace.	6 to 10 and more.	5 to 7	Possible traces of growth from drains.

Fine material in tertiary beds.

Beds would choke on surface every 2 years. We have had no experience of shallow filters of fine material, dealing with a strong liquor of this kind.

Septic tanks. 24 hours' continuous flow.

Septic Tank Liquor.

Ammoniacal nitrogen	8·0 to 8·5
Oxygen absorbed in 4 hours	13·0
Suspended solids	15·0 to 20·0

Strength 130.

Effluents.

	Triple contact beds.	Percolating filters of coarse material (deep).	Percolating filters of fine material (deep).	Good land.
Rate of filtration per cube yard per day	30 galls. (3 fillings)	50 galls.	25 galls.	—
Ammoniacal nitrogen	0·5	1·0	0·75	Considerable danger of nuisance from smell.
Nitric nitrogen	2·5 to 3·0	3·5	4·0	—
Oxygen absorbed in 4 hours	1·5	3·0 to 4·0	2·5 to 3·0	—
Suspended solids	Trace	6 to 10 and more.	5 to 7	—

Fine material in tertiary beds.

Beds would choke on surface every 2 years. We have had no experience of shallow filters of fine material, dealing with a strong liquor of this kind.

NOTES.—(1) The numbers given for "strength" of Sewage represent *approximately* the parts by we[illegible]
(2) "Oxygen absorbed in 4 hours" means oxygen absorbed in 4 hours at 27° C. (80° F.) fr[illegible] (3·94 grms. per litre), rendered acid with dilute sulphuric acid.
(3) All figures of analysis are stated in parts per 100,000.
(4) By a "deep" filter we mean one of 5 to 6 feet and upwards in depth; by a shallow [illegible] 3 feet. It would probably be inadvisable at the present time to build sewage filters o[illegible]

required to oxidize 100,000 parts.
ormal solution of permanganate of potash

is below 5 feet in depth and usually about
an 2 feet 6 inches.

(5) At first sight it may seem curious that the same figures of analysis should be given for the land effluents of this Class. It has, however, to be remembered that the mechanical straining effect of land is such that all liquors derived from the same sewage must necessarily be brought more or less into line, and, further, that volume of sewage is a more important factor in land treatment than strength.
(6) The figures of analysis for effluents refer to the effluents including their suspended solids.