RESTAURATOR

International Journal for the Preservation of Library and Archival Material

Volume 21 · Number 1 · 2000

München

RESTAURATOR
Vol 21 (2000), No 1, pages 1–54 ISSN 0034-5806

PUBLISHER:

K. G. Saur Verlag GmbH & Co KG,
Ortlerstr. 8, D-81373 München
Federal Republic of Germany
Tel (+49/89) 7 69 02-0
Telex 5 21 206 7 saur d
Fax (+49/89) 7 69 02-1 50

Komplementärin: R. R. Bowker (UK) Ltd., London (98,5 %) (Alleingesellschafter: Reed Publishing Ltd.)
Komplementärin: K. G. Saur GmbH, München (1 %)
Kommanditistin: Butterworth (Europe) Ltd., London (0,5 %)

ADVERTISING RATES:

Advertising rate card 2000
Advertising fact sheet with details of mechanical requirements and closing dates available upon request

Responsible for advertising:
Constanze Güldner,
K. G. Saur Verlag GmbH & Co KG,
Ortlerstr. 8, D-81373 München

SUBSCRIPTION RATES (INCL. POSTAGE):
per annum DM 398,–, öS 2905,–,
sFr 354,–
Single copies DM 120,– öS 875,–
sFr 107,–

BANKING:

K. G. Saur Verlag GmbH & Co KG,
München
Postbank München,
Kto.-Nr. 206 141-804 (BLZ 700 100 80)
Bayer. Hypotheken- und Wechselbank,
München, Kto-Nr. 5 803 388 662
(BLZ 700 200 01)

ISSUED:

March, June, September, December

RESPONSIBLE: Dr. Helmut Bansa

(∞)
Printed on acid-free paper

Production Editor and Typesetting:
Dr. Rainer Ostermann, Jakob-Klar-Str. 3,
D-80796 München

Printed in Germany by:
DANUVIA Druckhaus Neuburg GmbH
Nördliche Grünauer Str. 53
D-86633 Neuburg/Donau

Restaurator, 2000, 1–8
Printed in Germany · All rights reserved

RESTAURATOR
ISSN 0034-5806

An Ancient Writing Material: Birch-Bark and its Need of Conservation

by D.G. SURYAWANSHI

INTRODUCTION

In ancient period, the means of communication and dissemination of information were not known certainly, but the ancient man has always tried to express his power of speech in some form of written words. At the first instance the communication was done face-to-face through the aids of gestures, symbols and sound, which were gradually developed in the form of a language to be used to convey the knowledge of father to his son, that of Guru to disciple and to communicate.

But to pass on the knowledge from generation to generation through oral communication would not have been possible, hence the ancient man started to discover various kinds of writing materials to serve his purpose. At first, man started to communicate through the media of making marks on wet soil with wooden sticks. Soon after that, he started to print over the clay tablets and on the flat surfaces. He used stone and hard surfaces to engrave the letters and figures abundantly in stone age. With the discovery of metals he started to express his views and speech on various kinds of metallic plates. Papyrus, parchment, vellum and many other ancient materials were used in European Countries.

During the stone and metal ages, the people communicated to each other through these media. Stone and metal are durable materials and would communicate to the succeeding generation. The inscriptions on pillars, sheets of gold, silver, iron and copper are the examples of ancient writing media.

The use of convenient leaves and barks of trees came thereafter as writing materials. Among the leafy writing materials palm-leaf is the most important one in all the south and south-east Asian countries. Among the barks the birch-bark (Bhoja-patra) was used very abundantly in ancient and medieval periods. It was widely used in Kashmir and the northern part of the India. Many of the birch-bark manuscripts in Kashimiri language are available in several museums and libraries.

A few manuscripts still exist in Lenin library Moscow in their collections. In India, before the advent of paper sometimes in the 10th century, birch-bark was

RESTAURATOR (ISSN 0034-5806) is published quarterly by K. G. Saur Verlag GmbH & Co. KG, Ortlerstr. 8, D-81373 München, Germany.

RESTAURATOR

International Journal for the Preservation of Library and Archival Material
Vol 21 (2000), No 1, pages 1–54 ISSN 0034-5806

Contents

Indexed in:
Chemical Abstracts
Current Contents
IBR (Internationale Bibliographie der Rezensionen wissenschaftlicher Literatur)
Information Science Abstracts
Library Literature
Library Science
Social and Educational Science Citation Index

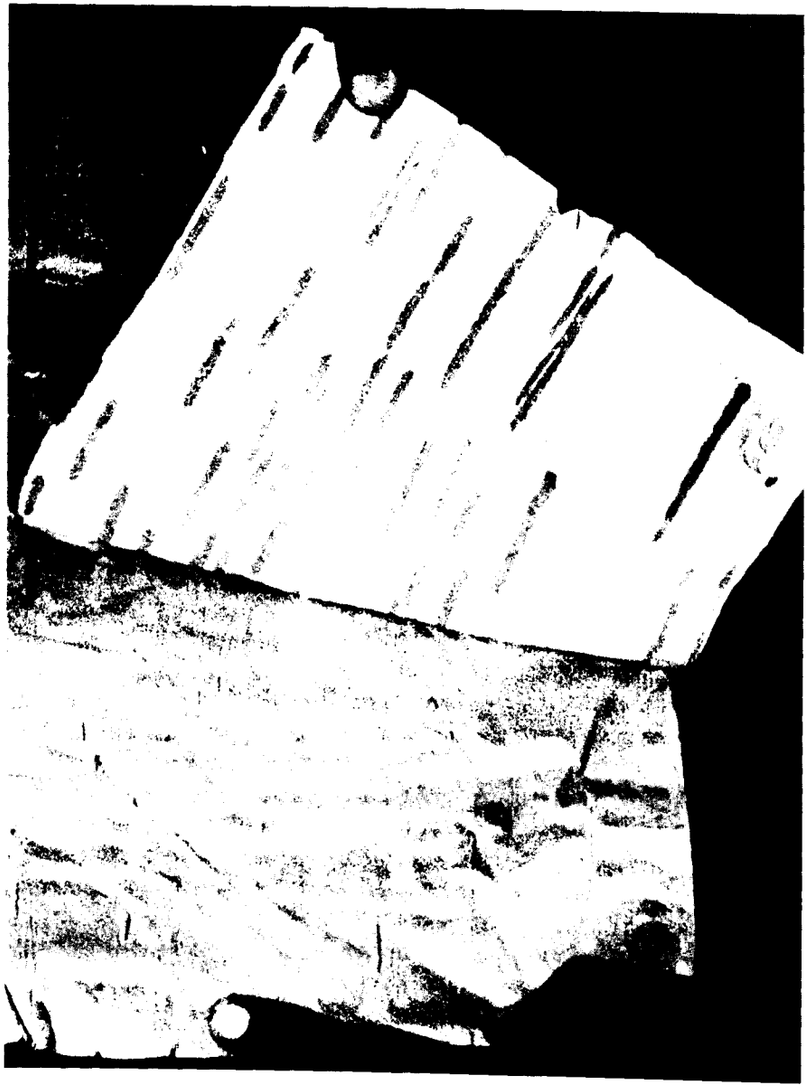

Fig. 1: Birch bark, separated in two layers.

used for writing purposes. The use of birch-bark was continued till the Mughal period and is being used today also for some purpose in Jammu and Kashmir[1,2]. Large collections of manuscripts are found in many Kashmiri houses.

BIRCH BARK

The bark is a natural, plant-origin organic product which is largely composed of many constituents. It gives very little resistance towards the atmospheric conditions and destructive agents. With the course of ageing, it is considerably decomposed; hence its protection is essential.

Origin of birch tree

The birch is a native of the colder regions of Europe and Asia, and throughout the whole of Russia, it is more common than any other tree being found in every wood. In the warmer countries it is found at high elevation in the mountains. In India it is found at the altitude of about more than 4000 m (14000 ft.) in Himalayas[3]. It varies in character according to the temperature.

The birch is a moderate sized deciduous tree, belonging to a natural order of *Amentaceae* under class *monoecia* and order *polyandria*[4]. The bark of the birch-tree is more durable than the wood. When the soil is very scanty, the trees are liable to be blown down, the bark remaining like a hollow cylinder without any symptoms of decay.

There is a number of species of birch tree, such as *Betula utilis*, the yellow birch (*Betula luta*), the habitat of which ranges from New England and the U.S. lake stages to Georgia, and the black birch (*Betual lenta*) which has a more restricted distribution. The white or paper birch (*Betula papyrifera*) is a more northern tree, found from the species of birch tree available at the sites of Himalaya and named as Himalayas silver birch[5].

The highlanders of Scotland make their houses, beds, chairs, tables, dishes and spoons out of birch wood.

Anatomy of birch bark

In everyday language the term "bark" means the outer part of the stem and branches which surrounds the wood. From the anatomical point of view, the concept "bark" includes all the tissues which are outside of the cambium[6].

The bark is divided into two kinds "inner bark" and the "outer bark". The function of the inner bark is to transport the nutrients and to serve as a storage organ for food reserves, whereas the outer bark principally consists of dead tissues and is thus physiologically inactive and only forms a protective layer against mechanical and chemical injuries. In the case of birch the lignified tissues of the inner bark constitute 20.3% of the whole. They are composed of sclerenchymatous tissue.

The cork tissue formed from the phellogen outward consists of scale-like cells, the cork cells, arranged in radial rows[7]. These cells are cemented together by means of an alkali soluble substance. This type of structure constitutes the cork tissue and makes it difficult to be penetrated by water and gases. The walls of cork cells which are very thin and rarely pitted, consist of three layers, the outermost composed of lignified cellulose with an intermediate supersized lamella. In some other tree species (all birch), the walls of the cork cells also contain, in addition to suberin, a substance called betulin which gives the bark its white colour. The cork cells die at a very early stage and become filled with air, primary cork which for several years covers both branches and stem, grows very thick in some species and differentiates into successive layers, some being tighter and other looser. The separation of the different layers is due to the fact that cork cells formed in the late summer have thick walls and are more compressed that those formed in the spring.

In the cork tissue, there are areas that allow the penetration of air into the living bark tissue. These mostly roundish, limited spots, where the cork cells are not completely cemented together, are named lenticells[8].

The cortex tissue is mainly composed of thin walled parenchymatous cells, separated by large intercellular spaces; these cells in many cases lignify and become to resemble scleroid cells. Cortex tissue may also include resin canals or "secretary" cells. Between the cortex and the epidermis or periderm there is often a zone composed of collenchymatous or collenchyma like cells. In certain trees like *Betula papyrifera* (white-birch) the cortex tissue still persists when the stem has completely matured[9].

Process of bark removal

For removing the bark from the tree, two circular incisions are made quite through the bark several feet from each other. Two verticals incisions are then made on opposite sides of the tree after which a wooden wedge is introduced by which the bark is easily detached in plates usually 10 or 12 feet long and 2–9 inches broad.

Utility of birch-bark and its essential oil

The thin white bark of the common birch, which peels off like paper is highly inflammable and will burn like a candle. It contains an oil which can be extracted. In Russia it is used in the preparation of Russian leather[10, 11].

The extraction process works as follows: The white bark, either from freshly cut or decayed trees which are found in the wood, is pressed into a big cone-shaped vessel having a hole compared to a funnel, covered with turf and heated. The oil which trickles down inside this vessel is collected in a bottle or a jug placed under its hole and then stowed away in casks. The purest oil swims at the surface, and when it is rubbed into an animal's skin, it has a tanning effect, changing the skin to be leather, and giving it a typical odour: fragrant for the human nose, but repelling for insects and microorganism. Books bound in Russian leather are not only not liable to become mouldy; they even prevent mouldiness in books which happen to be near to them.

Birch bark or its oil resp., can also be used to prepare a sweet juice, for conditioning wine, preparing root beer, and other purposes. The bark which peels off in characteristic layers finds a use in the manufacture of canoes and fancy articles of various kinds. According to Pliny, the branches of the birch tree were used for making baskets, loops of casks, panels and for preparation of charcoal[11]. He is mentioning a highly fragrant kind of resin exuding from leaves and young twigs, especially after rain or heavy dew, which has been collected and used as "bitumen"[11, 12]. The odour arising from it is perceptible to a person passing nearly a tree.

CONSERVATION PROBLEMS

Separation of thin layers

The Birch-bark is composed of several layers, each of which is very thin and joined together by a natural adhesive and by knots and streaks. During ageing, the efficiency of the adhesive is lost and the fixed layers start to separate from each other. Refixing again with the same material is very difficult. This is one of the main conservation problems for birch bark manuscripts and we have attempted to address it.

Sticking of sheets

With ageing and due to the wrong storage of birch-bark manuscripts, the folios get stuck together. It is very difficult to separate them from each other and if even a slight force is applied a considerable damage can occur.

Handling

Birch bark objects are considerably weak and must be handled with extreme caution. They have lost their initial flexibility and have become stiff and brittle. It can happen that such sheets even with slight lifting crumble into pieces.

Cleaning

Birch bark is a natural organic product of vegetable origin, which is compounded with many constituents like cellulose, lignin, gum, resins and many other unknown products. Therefore, its cleaning with organic solvents is highly problematic, because the solvent can leach out some of the components which may be protective to the bark.

Removal of acidity

Acidity is an insidious foe to documents of any kind, and though its removal is possible in paper up to some extent, it is very difficult for birch-bark. Alkaline substances affect the band structure between the layers of bark and, as a result of a relevant treatment, they will be separated from each other. Rejoining is very difficult, as already reported.

Rejoining separated layers

Aqueous solution of methyl cellulose (Glutofix™600) in very low concentration (1,5–2.5%) is applied with a fine brush. It penetrates through the layers which then must be kept under slight pressure between blotting paper at room temperature. After 3–4 hours they are dry and joint together firmly enough to tolerate gentle handling.

Other problems

Besides these, there are many other problems with birch-bark manuscripts, comparable to the problems with palm leaf and even more to those with papyrus. Hardly anything can be done against discolouration, fading of inks, etc. Curled edges can be carefully flattened; indirect moistening before doing so may help to prevent a break. Tears can be repaired in the same manner as it is done with paper, but the result will hardly be as inconspicuous as a good result in paper. For storage and exhibition birch bark that has become brittle should be mounted under or between transparent plates (acrylic glass, polycarbonate), if already broken to pieces, then positioned in an exactly custom-made frame of paper of the same thickness as the bark, in order to prevent the pieces from slipping.

CONCLUSION

Birch-bark manuscripts are not easily affected by insects and fungus and are not perishable under the normal atmospheric conditions of a good room climate. This is due to some organic constituents which are repellent to the insects and fungus. This unique property of birch bark encourages the scientist to go to detailed physico-chemical studies.

ACKNOWLEDGEMENTS

The author is very thankful to the NRLC Library staff, especially to Mr. Devendra Kumar who helped in finding the references.

SUMMARIES

An Ancient Writing Material: Birch-Bark and its Need of Conservation

Birch bark has been used for many purposes, one of them being as writing material. In India it was common until the advent of paper in the 10th century, continued to be used till the Mughal period (16th century), and in Kashmir it is still used for some purposes until today.

The structure of the bark and the process to prepare it for writing is described. The main conservation problems are separation of the several layers and brittleness. Separated layers can be rejoined using methyl cellulose in very low concentration. Brittle sheets should be mounted under or between transparent plates of acrylic glass or poylcarbonate. As a result of wrong storage it can happen that several sheets stick together and can hardly be separated without the risk of damage and loss.

Un ancien matériau utilisé comme support pour l'écriture : l'écorce de bouleau et les moyens qu'exige sa conservation

L'écorce de bouleau a été utilisée à des fins multiples dont celui de support pour l'écriture. En Inde son utilisation était courante jusqu'à l'avènement du papier au 10ème Siècle, son utilisation a duré jusqu'à l'Empire Moghol (16ème Siècle) et au Cachemire on s'en sert encore aujourd'hui à certaines occasions.

On décrit la structure du bouleau ainsi que le processus de préparation nécessaire pour le rendre apte à servir de support pour l'écriture. Les principaux problèmes rencontrés au niveau de la conservation résident dans la séparation des différentes couches et leur fragilité. Il est possible de

réassembler les couches qui se détachent à l'aide de cellulose de méthyle dans une solution aqueuse fortement diluée. Les feuilles cassantes devraient être montées sous ou entre des plaques (pellicules) transparentes de verre acrylique ou de polycarbonate. En cas d'entreposage inadapté il se peut que plusieurs feuilles se collent les unes aux autres de telle sorte qu'il est presque impossible de les détacher les unes des autres sans risquer de les détériorer ou de les détruire.

Ein historischer Beschreibstoff: Birkenrinde und ihre konservatorischen Anforderungen

Birkenrinde wurde für manche Zwecke verwendet, u.a. als Beschreibstoff. In Indien war sie bis zum Aufkommen des Papiers im 10. Jh. allgemein üblich, stand neben Papier bis in die Mogulzeit (16. Jh.), und in Kaschmir wird sie für bestimmte Zwecke bis heute eingesetzt.

Es werden der Aufbau der Rinde und die Maßnahmen beschrieben, die notwendig sind, um aus ihr einen Beschreibstoff zu machen. Die Hauptprobleme der Konservierung sind die Trennung der einzelnen Schichten und das Brüchigwerden. Getrennte Schichten kann man mit Hilfe von Methylcellulose in stark verdünnter wäßriger Lösung wieder zusammenfügen. Brüchige Blätter sollten unter oder zwischen transparenten Platten aus Acrylglas oder Polycarbonat montiert werden. Bei falscher Lagerung können die einzelnen Blätter so miteinander verkleben, daß sie sich kaum ohne Beschädigungs- und Verlustgefahr wieder voneinander trennen lassen.

References

1. Agarwal, O.P.: *Conservation of manuscripts and paintings of South-East Asia 1.* London: Butterworth 1984: 11–13.
2. Agarwal, O.P.: *Birch bark manuscripts.* Museum 27 (1975): 166.
3. Brandis, D.: *Indian trees.* Dehradum: Bishem Singh Mahendra Pal Sing 1971: 622.
4. Rendle, Alfred Barton: *The classification of flowering plants 2.* Ghaziabad: Vikas 1979: 24–29.
5. Singh, Gurcharan, & P. Kachroo: *Forest flora of Srinagar: Betula Utilis.* Denradun: Bishen Singh Manencra Pal Singh 1976: 58.
6. Chang, Y.P.: *Anatomy of common North American pulp wood barks.* Tappi Monograph Series 14 (1954): 58.
7. Esau, K.: *Plant anatomy.* New Delhi: Wiley Eastern 1974: 348.
8. Roth, Ingrid: *Structural patterns of tropical barks.* Encyclopaedia of Plant Anatomy. Berlin: Bornträger 1981: 112.
9. Browning, B.L.: *The chemistry of wood.* Huntington, NY: Robert E. Krieger 1975: 600, 604.
10. Dastur, J. F.: *Useful plants of India and Pakistan.* Bombay: D.B. Taraperevala 1964: 35.
11. Hill, Albert F.: *Economic botany. A text book of useful plants and plant products.* New Delhi: Tata McGraw-Hill 1972: 68–70.
12. Jenson, W.: *Chemical characteristics of bark and wood.* Acta Acad. Aboensia, Math., Phys, 16 (1948): 3.

D.G. Suryawanshi
National Research Laboratory for Conservation of Cultural Property
E/3, Aliganj Scheme
Lucknow - 226 024
India

Restaurator, 2000, 9–18
Printed in Germany · All rights reserved

RESTAURATOR
ISSN 0034-5806

The Effect of Nd:YAG Laser Radiation at 1064 nm on Paper

by JANA KOLAR, MATIJA STRLIČ, MARKO MARINČEK

Introduction

Cleaning of artefacts by laser irradiation offers contactless removal of dirt and stains without the use of eraser or solvents. These characteristics make the method particularly appealing for conservation of historic documents and a series of recent publications discuss the use of various lasers for conservation of paper and parchment[1–6].

With the Nd:YAG laser at 1064 nm and fluences of 29 Jcm^{-2} Caverhill *et al.*[2] successfully removed several different types of inks from paper artefacts, however, the treatment increased degradation of paper during accelerated ageing test[4]. While their choice of analytical methods was somehow unfortunate, the authors suggested that the marked oxidative deterioration of paper was induced by the long pulse duration (70–150 ns) which may result in overheating of the substrate.

In this work, the immediate and long term effect of Nd:YAG laser at 1064 nm and pulse duration of 6 ns on cellulose and paper is reported.

Experimental

Paper samples used in this study were Whatman filter paper (DP 2632.3±19.4, brightness 89.92%±0.06) and gelatine sized rag paper from year 1600 (pH 4.6 (Tappi T509 om-88), DP 890.8 and brightness 50.67%, ash content 0.01% (Tappi T413-93)).

DP was calculated from cellulose viscosity measured according to SCAN 15:88 standard.

Brightness (reflectance at 457 nm) was determined with Minolta CM-3610d spectrophotometer.

Thermal treatment was performed in a humidity chamber at 90°C and 65% relative humidity.

Diffuse reflectance FTIR (DRIFT) spectra were obtained with BIO-RAD FTS 15/80 spectrometer equipped with a DRIFT cell (Harrick Scientific, Ossining NY, U.S.A.) using KBr as background.

A Q-switched Nd:YAG laser at 1064 nm with a pulse duration of 6 ns and rize time 1–2 was used for treating the samples. The output beam was of an uniform "top hat" profile with a spot diameter of 8 mm and the maximum fluence up to 1.5 Jcm^{-2}. Higher fluences were obtained by focusing the beam through a plano-convex lens. The peak power at the maximum output energy is estimated to be about 125 MW. The maximum laser repetition rate is 20 Hz, however, for this evaluation the laser was operating in a single shot regime.

Results and Discussion

Immediate effect of the laser treatment

Under ambient conditions, water vapour is absorbed on fibrillar surfaces and in less ordered regions of the cellulose. Thus, the water content in amorphous cellulose is 18.17%[7] at 59% RH and 21°C. Water molecules absorb radiation from

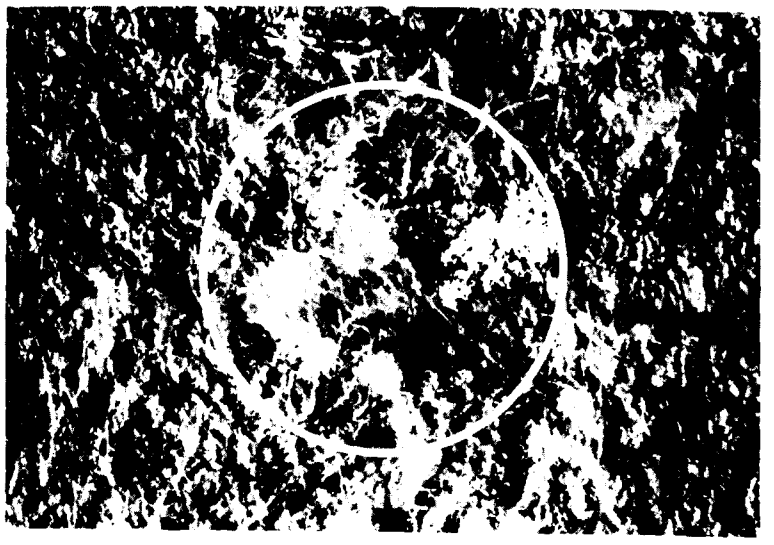

Fig. 1: Laser treatment (ca. 4 Jcm^{-2}) indused disruption of the surface of gelatine sized rag

Nd:YAG laser at 1064 nm more strongly (absorption coefficient 0.6 cm^{-1})[8] than in case of other lasers used in paper conservation (Nd:YAG 532 nm[1] and Excimer 308 nm)[6]. Therefore, instantaneous, even explosive vaporization of water is more likely to occur during the treatment at 1064 nm, thus damaging the paper structure.

Severe distortion of the paper surface is observed already at fluences of about 4 Jcm^{-2} (Fig. 1), while a slight disruption was reported by Caverhill *et al.*[2] to occur only above 18 Jcm^{-2}. This distinction may be caused by a different duration of a laser pulse employed in the two studies (6 and 90–150 ns, respectively) or a smaller spot size (8 mm and 0.14 mm, respectively) of the laser beam, which could somewhat limit the observation of physical damage induced by the treatment.

Due to the detrimental effects of higher fluences, only the ones up to 1.5 Jcm^{-2} were evaluated in this study.

In case of Whatman filter paper the treatment resulted in a slight increase of brightness (up to 0.5%, Fig. 2) as well as of degree of polymerization (DP; up to 1.9%) while irradiation of gelatine sized rag sample by laser beam increased DP by almost 8%.

While an increase of brightness could be caused, for example, by removal of some impurities from the surface of paper, increase of DP as a result of laser treatment could only be explained by chemical cross-linking. Dehydration reac-

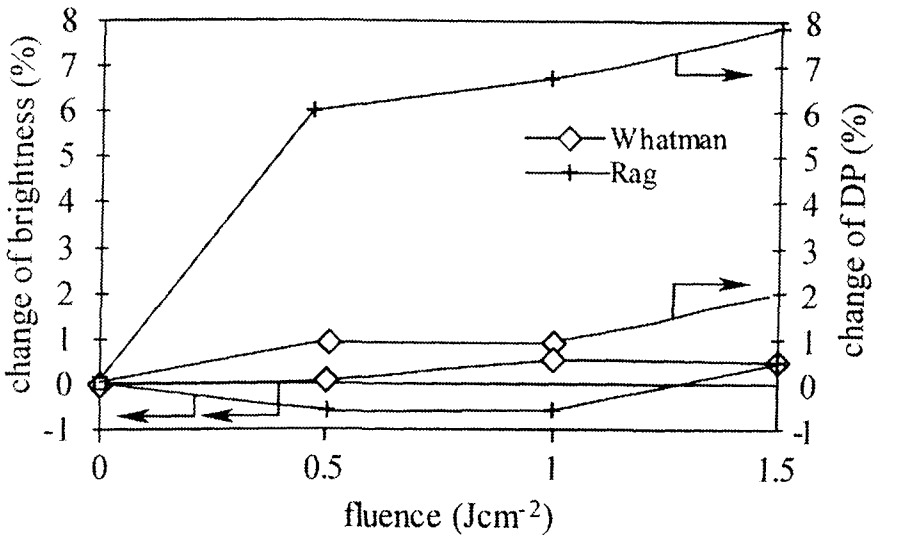

Fig. 2: Brightness and DP of untreated and laser irradiated Whatman and rag paper samples before accelerated ageing.

tions, leading to the formation of predominantly ether bonds, have been known to occur during thermal treatment of cellulose[9]. Intermolecular cross-linking of cellulose molecules is not a desired reaction as it has been reported to result in a rapid loss of tensile strength, due to reduction of the proportion of molecules in a fibre that can be fully extended simultaneously when stress is applied[7].

Diffuse reflectance FTIR spectroscopy may offer valuable qualitative insight into changes in the chemical composition of surface. Of particular interest is the spectrum obtained by subtraction of DRIFT spectra of the treated and untreated paper, where the untreated control was used as a reference (Fig. 3). The difference is remarkably small, especially in the region between 1700 and 3000 cm^{-1}, indicating that the content of acidic or carbonyl groups (characteristic band at 1730 cm^{-1})[10] does not change during laser treatment under described conditions. Differences in hydroxyl group content are difficult to establish due to high noise in the corresponding wave number region. Since the spectra were recorded a few days after the laser treatment, only a slight difference in adsorbed water content is indicated (1660 cm^{-1})[10], confirmed also by determinations of moisture content. On the other hand, the fingerprint region shows considerable differences. The composite positive absorption band at 980–1170 cm^{-1} can be assigned to C-O stretching, ring stretching and C-O-C asymmetric stretching[10] and indicates formation of C-O and/or C-O-C bonds. The negative bands at 1189, 1219, 1385 and 1450 cm^{-1} can be assigned to C-O-H bending[10,11]. Both features are in accordance with the positive changes in DP following laser treatments and indicate formation of intra- and intermolecular ether bonds by dehydration.

Long term effects of the laser treatment

Substantial yellowing of the laser-treated surface has been reported after only one day of thermal accelerated ageing at 90°C and 50% RH. In our study, laser treatment induced only a slight decrease of brightness of gelatine sized rag paper (0.7% for the paper irradiated with the highest fluence). Laser-treated Whatman filter paper on the contrary, displayed increased brightness stability (by 1.9% for paper irradiated with 1.5 Jcm^{-2}) as compared to the untreated control (Fig. 4). This contradictory behaviour of the two papers may be caused by the interaction of the gelatine size in rag paper with the laser beam, as reported by Caverhill *et al*[4].

It has long been known that degradation of pure cellulose during ageing results in discoloration of paper, as chromophores which absorb in the blue/violet region are formed[12]. A decrease of brightness (diffuse reflectance at 457 nm) during accelerated ageing experiment could therefore be related to the extent of

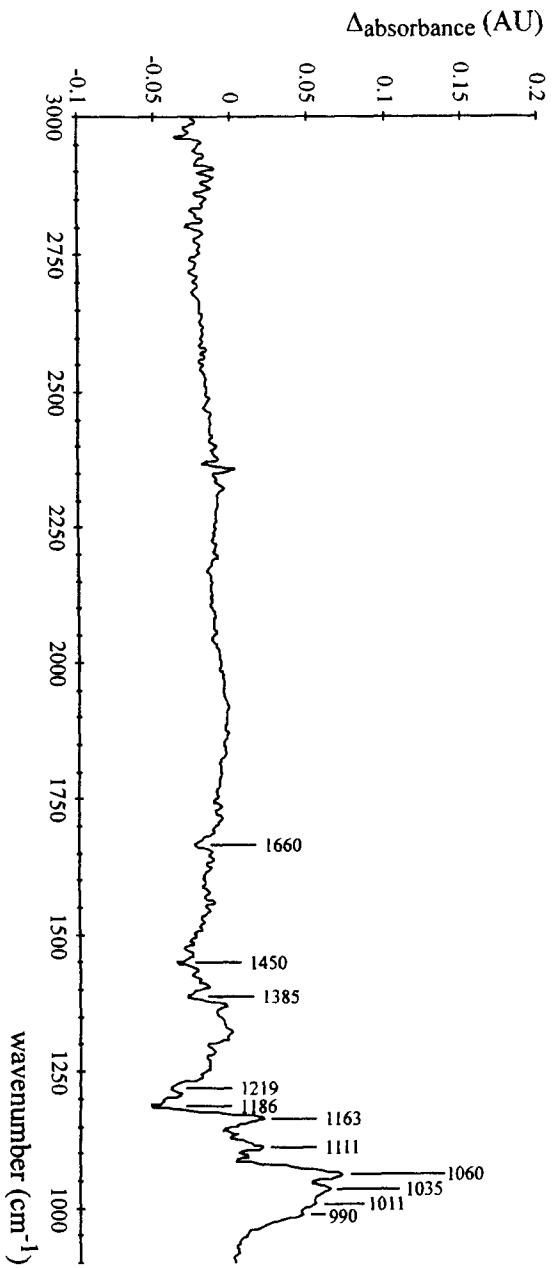

Fig. 3: DRIFT subtraction spectrum of a laser treated Whatman paper sample (fluence: 1.0 Jcm^{-2}); reference: untreated control.

degradation of the material. In fact, a relatively good correlation has been found between decrease in DP and brightness during 28 days of accelerated ageing (80°C, 65% RH) for a variety of cellulose pulps[13].

Therefore, the results presented in Fig. 4 suggest, that the laser treatment stabilized purified cellulose (Whatman) during accelerated ageing. This was confirmed by the viscosity measurements (Fig. 5), where a marked stabilization of Whatman paper as a result of the laser treatment is observed.

As with brightness determination, rag paper behaved somewhat differently from the purified cellulose. Laser treatment resulted in substantial immediate increase of DP (by ca. 7%) and the papers retained the high DP values even after 3 days of accelerated ageing. After this initial period, the viscosity of laser beam-irradiated rag paper decreased substantially and the overall effect was in favour of untreated control. Although the rag paper degraded strongly during the 6 days ageing period (16%), the differences between samples are only minor ones and longer ageing periods would be necessary for a more apt evaluation of the stability of this composite material.

Unfortunately, at the conditions employed in this study, ball-pen inks tested were not affected by the laser treatment. However, carbonaceous dirt was successfully removed (Fig. 6).

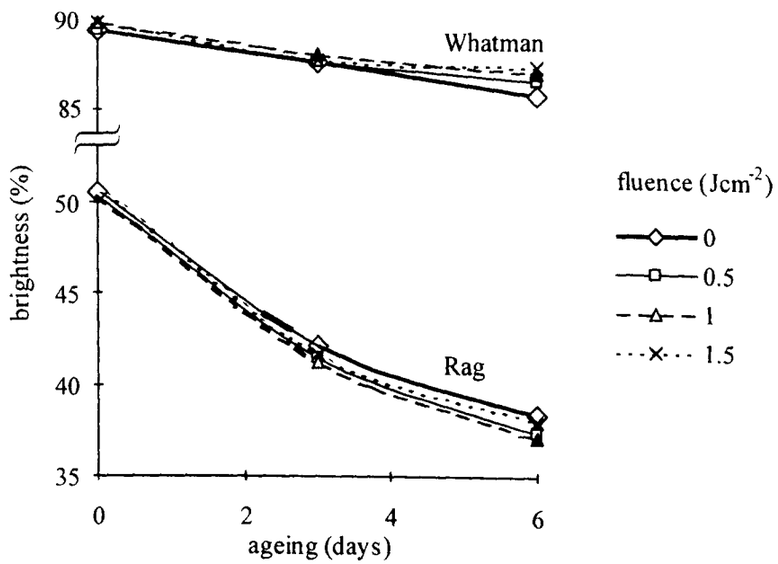

Fig. 4: Brightness of Whatman and rag paper after thermal accelerated ageing (0-untreated, 0.5, 1, 1.5 denote the fluences used).

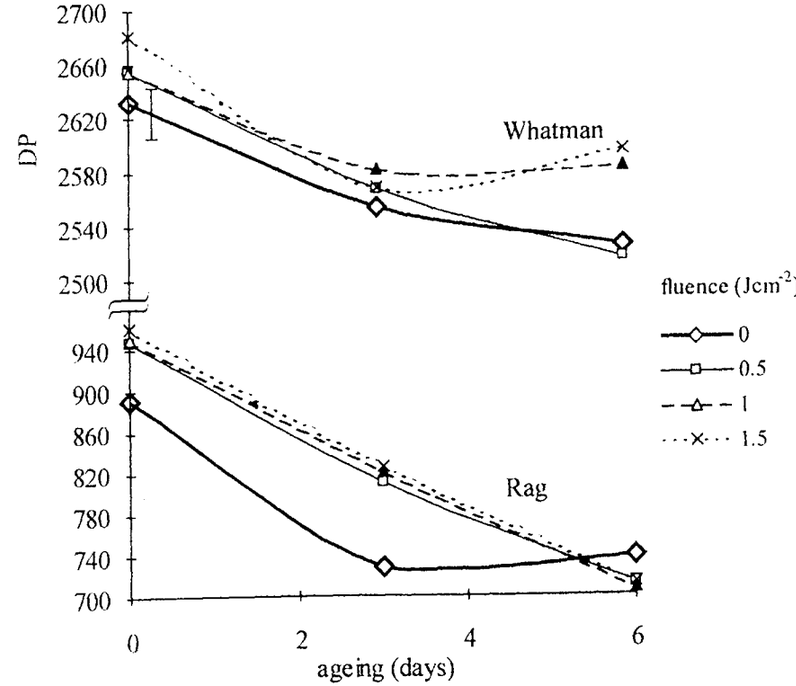

Fig. 5 (above): Ageing stability of Whatman and rag paper (0-untreated, 0.5, 1, 1.5 denote the fluences used).

Fig. 6 (left): Removal of carbonaceous dirt by irradiation of paper with Nd:YAG laser at 1064 nm and 1.5 Jcm^{-2}.

Conclusion

Laser treatment of Whatman as well as gelatine sized rag paper increased DP values of samples. This suggests that irradiation of paper induces formation of inter-molecular cross-links between cellulose molecules, which is supported by an increase in absorption bands ascribed to ether bonds in diffuse reflectance FTIR spectra. No discernible difference in spectra around 1730 cm^{-1} indicate that change in content of acidic or carbonyl groups during laser treatment under described conditions is below threshold sensitivity of the method.

It appears that irradiation of paper with laser beam at 1064 nm stabilised Whatman filter paper during accelerated ageing, as brightness and DP values of the treated samples remained higher than the untreated control. Results were different for gelatine sized rag paper as the brightness and DP after 6 days of accelerated ageing at 90•C and 65% RH were slightly lower in case of treated papers.

Results presented here indicate that Nd:YAG laser at 1064 nm is a potentially useful tool in paper conservation. However, before the method may be applied to historical documents, additional information must be obtained, especially regarding the effects that it exhibits on mechanical properties of paper. Additional studies must also incorporate a variety of different paper samples, as well as the effect on iron-gall ink regions. This work is in progress.

Summaries

The Effect of Nd:YAG Laser Radiation at 1064 nm on Paper

Immediate as well as long term effects of Ng:YAG laser irradiation at 1064nm, pulse duration of 6 ns and fluence up to 1.5 Jcm^{-1} on paper is reported.

Results of diffuse reflectance FTIR spectroscopy show no discernible difference in the regions around 1730 cm^{-1} indicating that change in content of acidic or carbonyl groups during laser treatment under described conditions is below threshold sensitivity of the method. However, positive absorption bands as a result of laser treatment may be ascribed to C-O and C-O-C vibrations, suggesting the formation of intra- and intermolecular ether bonds. Results of DP are in accordance with DRIFT spectroscopy, as the cross-linking of cellulose during the treatment results in an increase of DP of cellulose.

L'effet d'une irradiation au laser de Néodyme:YAG de 1064 nm sur le papier

Un rapport a été réalisé sur les effets immédiats ainsi que sur le long terme d'une irradiation au néodyme:yttrium-aluminium-grenat d'une longueur d'onde de 1064 nm, d'une durée d'impulsion de 6 ns et d'une force allant jusqu'à 1,5 Joule/cm^{-1} de papier.

Les résultats observés grâce à la spectroscopie DRIFT (Diffuse Reflection Infrared Fourier Transform) n'indiquent pas de différence discernable aux alentours de 1730 cm^{-1}, ce qui permet de conclure que le changement de la teneur en acide ou en groupes carbonyles au cours du traitement d'irradiation dans les conditions décrites se situe au-dessous du seuil de sensibilité de la méthode. Les bandes d'absorption positives observées après le traitement au laser pourraient être attribuées aux vibrations C-O et C-O-C laissant supposer la formation de réactions intra- et intermoléculaires. Les mesures du degré de polymérisation concordent avec les résultats de l'étude réalisée avec la spectroscopie DRIFT car les effets réticulaires sur la cellulose au cours du traitement au laser se traduisent par une augmentation du DP (pitch diamétral).

Die Wirkung von Nd:YAG Laser 1064 nm auf Papier

Es wird berichtet über die Effekte, die eine Bestrahlung mit Neodym:Yttrium-Aluminium-Granat Laser von 1064 nm Wellenlänge, Pulsdauer 6 ns und Stärke bis zu 1.5 Joule pro cm auf Papier hat, sowohl unmittelbar als auch längere Zeit danach.

Untersuchungen mit DRIFT-Spectroskopie (Diffuse Reflection Infrared Fourier Transform) zeigen keinen merklichen Unterschied in Bereichen um 1730 cm^{-1}, woraus zu entnehmen ist, daß Veränderungen im Gehalt an Säure oder Carbonylgruppen unterhalb der Empfindlichkeitsgrenze der Methode liegen. Positive Absorptionsbanden, die nach der Laser-Behandlung zu beobachten sind, könnten jedoch auf C-O- und C-O-C- Schwingungen und damit auf die Ausbildung von inner- und zwischenmolekularen Bindungen hinweisen. Messungen des Polymerisationsgrades finden eine Entsprechung in den Ergebnissen der Untersuchung mit DRIFT-Spektroskopie, da sich die Vernetzungseffekte, die durch die Laserbehandlung an der Cellulose hervorgerufen werden, in einer Zunahme des DP auswirken.

References

1. Szczepanowska, H. M. & W. R. Moomaw: *Laser stain removal of fungus-induced stains from paper.* JAIC 33 (1994): 25–32.
2. Caverhill, J., I. Latimer & B. Singer: *An investigation into the use of a laser for the removal of modern ink marks from paper.* The Conservator 20 (1996): 65–75.
3. Caverhill, J., B. Singer & I. Latimer: *An investigation into the use of lasers in paper conservation.* In: Proceedings of the fourth international conference of the Institute of Paper Conservation, London. Leigh, Worcester, UK: Institute of Paper Conservation, 1998: 284–90.
4. Caverhill, J., J. Stanley, B. Singer & I. Latimer: *The effect of ageing, on paper irradiated by laser as a conservation technique.* Restaurator 20 (1999): 57–76.
5. Rudolph, P., S. Pentzien, J. Krüger, W. Kautek & E. König: *Laserreinigung von Pergament und Papier. Experimente an Modellsystemen und historischen Originalen.* Restauro 6 (1998): 396–02.
6. Kautek, W., S. Pentzien, P. Rudolph, J. Krüger & E. König: *Laser interaction with coated collagen and cellulose fibre composites: fundamentals of laser cleaning of ancient parchment manuscripts and paper.* Appl. Surf. Sci. 127–129 (1998): 746–54.
7. Nevell, T. P. & S. H. Zeronian (Eds.): *Cellulose chemistry and its applications.* Chichester, England: Ellis Horwood Limited, 1985.

8. Luck, W. A. P.: *Zur Assoziation des Wassers. III. Die Temperaturabhängigkeit der Wasserbanden bis zum kritischen Punkt.* Ber. Bunsenges. Phys. Chem. 69 (1965): 626–37.
9. Chamberlain, D. C. & D. J. Priest: *Identity of cross-links in thermally-aged paper.* Cellul. Chem. Technol. 30 (1996): 329–34.
10. Fengel, D. & M. Ludwig: *Possibilities and limits of the FTIR spectroscopy for the characterization of cellulose. Part 1. Comparison of various cellulose fibres and bacteria cellulose.* Papier 45 (1991): 45–51.
11. Lide, D. R. (Ed.): *CRC handbook of chemistry and physics*, 71st ed., Boca Raton, USA: CRC Press, 1990.
12. Hon, D. N.-S.: *Yellowing of modern papers.* In: Williams, J. C. (Ed.) Preservation of paper and textiles of historic and artistic value II. Advances in Chemistry Series, 193. Washington, DC: American Chemical Society, 1981: 119–42.
13. Kolar, J.: *Effect of conservation treatments on ageing stability of cellulose.* Ph.D. thesis, University of Ljubljana, 1998.

Jana Kolar
National and University Library
Turjaška 1
SI-1000 Ljubljana, Slovenia
phone: +386 61 2001114
fax: +386 61 1257293
jana.kolar@nuk.uni-lj.si

Matija Strlič
University of Ljubljana, Faculty of Chemistry and Chem. Technol.
Aškerčeva 5
SI-1000 Ljubljana, Slovenia
phone: +386 61 1760543
fax: +386 61 1258220
matija.strlic@uni-lj.si

Marko Marinček
Fotona d.d.
Stegne 7
SI-1210 Ljubljana, Slovenia
phone: +386 61 1511215
fax: +386 61 1511576
marko.marincek@fotona.si

Restaurator, 2000, 19–24
Printed in Germany · All rights reserved

RESTAURATOR
ISSN 0034-5806

Exhibition and Transportation of the Dead Sea Scrolls

by ESTHER BOYD-ALKALAY & LENA LIBMANN

INTRODUCTION

Within the framework of the conservation and preservation of the Dead Sea Scrolls at the laboratory of the Israel Antiquities Authority we have considered how to store and exhibit the Scrolls[1]. The question arose whether the scrolls should be enclosed in completely sealed frames made of polycarbonate plates for exhibition and transportation or be placed in containers with openings for ventilation, as is widely practised. This report describes experiments carried out in order to answer this question.

EXPERIMENTS

For experiments 1 and 2, two kinds of frames were made, measuring 25 x 15,5 x 3 cm^3 (Fig. 1). In Frame 1, 25 evenly spaced holes of 0,7 cm in diameter were drilled; Frame 2 remained intact. A small fragment of parchment was placed into each frame, as well as a thermometer and hygrometer. The frames were placed next to each other under the same conditions until their temperature and relative humidity had stabilized.

In Experiment 1, both frames were equally elevated above the table in order to allow air circulation. The room was without strict climate control. The fluctuation in temperature and relative humidity within the frames over 15 days are given in Table 1.

In Experiment 2, both frames were placed inside a plastic container and were elevated from the bottom. Two glasses of water covered with damp cloths were put between the frames. The plastic container was hermetically sealed with polystyrene film (see Fig. 2 and 3). At the beginning of the experiment the frames had the following temperature and relative humidity:

- Frame 1: 25°C, 55%
- Frame 2: 24°C, 50%

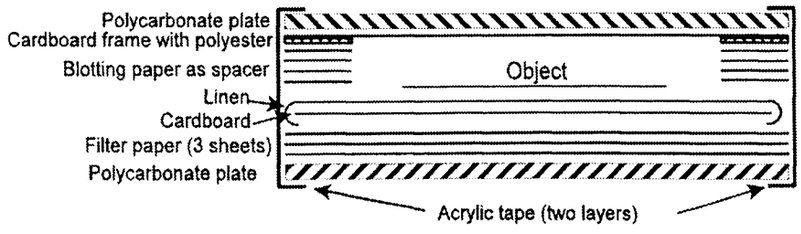

Fig. 1: Structure of the frames.

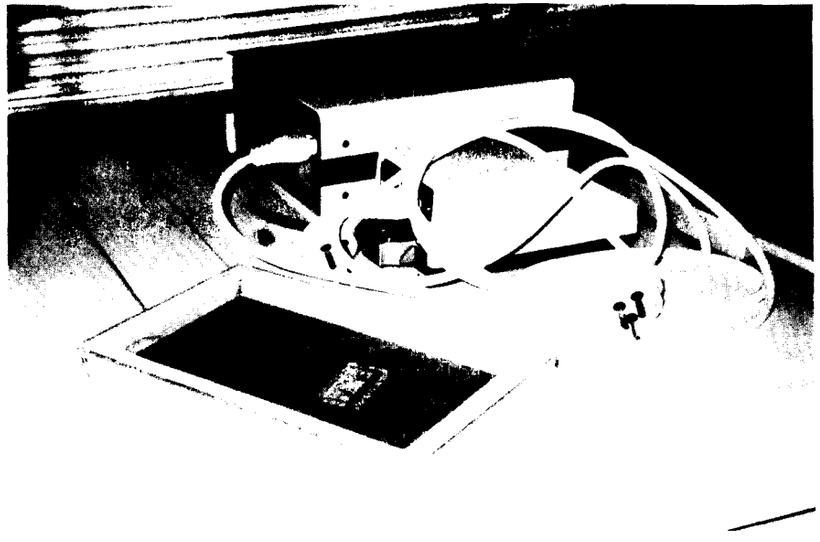

Fig. 2: A frame.

The changes in temperature and relative humidity within the boxes over 15 days are shown in Table 2.

At the end of the experiment the relative humidity inside the plastic container had reached 100%.

For Experiment 3, three new frames were made identical to the previous ones, except that in Frame 3 15 equally spaced holes were drilled of diameter 0,7 cm in order to test the effect of the number of holes. When the temperature and relative humidities in the frames had stabilised they were placed inside an electric kiln with a constant internal temperature of 40°C. As before, the changes in temperature and relative humidity inside the frames were recorded (Table 3).

These three experiments were performed in order to determine the influence of the environment on frames with or without ventilation holes, first in a room

Table 1: Climatic data of Experiment 1: Frames exposed to air circulation.

Date	Frame 1 (25 holes)				Frame 2 (no holes)			
	Morning (9 am)		Evening (4 pm)		Morning (9 am)		Evening (4 pm)	
	T (°C)	RH(%)	T (°C)	RH(%)	T (°C)	RH(%)	T (°C)	RH(%)
17.8.98	24	51	24	51	22	49	22	49
18.8.98	26	52	25	50	23	48	22	48
19.8.98	26	51	24	49	24	49	22	50
20.8.98	26	48	23	49	22	48	21	50
23.8.98	24	49	24	49	22	49	22	49
24.8.98	24	54	25	55	22	49	22,5	49,5
25.8.98	25	57	25	55	22	49,5	23	50
26.8.98	25	55	24	56	23	50	23	51
27.8.98	24	57	24	56	22	51	22	50
30.8.98	24	57	24	56	22	51	22	51
31.8.98	24	56	23	57	22	51	51	50

Table 2: Climatic data of experiment 2: Frames exposed to damp surroundings.

Date	Frame 1 (25 holes)				Frame 2 (no holes)			
	Morning (9 am)		Evening (5 pm)		Morning (9 am)		Evening (5 pm)	
	T (°C)	RH(%)	T (°C)	RH(%)	T (°C)	RH(%)	T (°C)	RH(%)
1.9.98	25	55	24	59	24	50	22	50
2.9.98	24	62	24	70	22	50	22	50
3.9.98	24	70	24	70	22	50	22	50
6.9.98	25	85	24	86	23	52	22	54
7.9.98	24	87	23	89	24	53	22	54
8.9.98	24	87	23	91	23	53	22	54
9.9.98	24	90	22	91	22	52	22	54
10.9.98	25	91	24	91	23	54	22	54
13.9.98	24	91	24	95	22	55	23	56
14.9.98	24	95	24	95	22	56	22	56
15.9.98	24	95	23	95	22	56	22	56

without strict climate control, second in a space with relative humidity up to 100% and third in a space of temperature 40°C. All three possibilities can occur when the climate control in the storage or exhibition hall fails or during transport or disaster.

Experiment 1 shows that the changes in temperature and relative humidity in the closed box are slight: in Frame 1 the temperature varied by 2 degrees and the relative humidity by 9%. In Frame 2 the temperature varied by 2 degrees

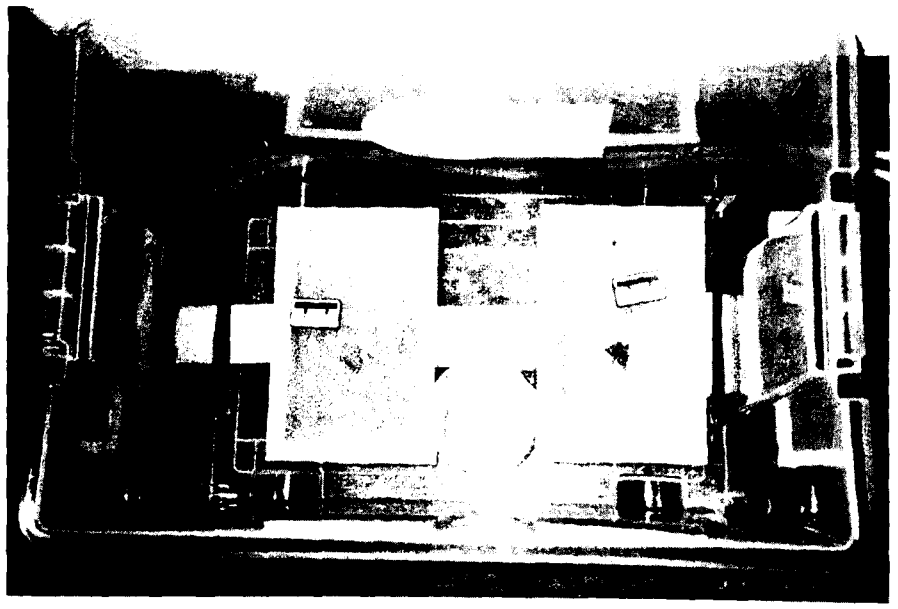

Fig. 3 and 4: Arrangement of the frames for experiment 2, top view and side view.

Table 3: Climatic data of experiment 3: Frames exposed to elevated temperature.

Date	Time	Frame 1 (25 holes)		Frame 2 (no holes)		Frame 3 (15 holes)	
		T (°C)	RH (%)	T (°C)	RH (%)	T (°C)	RH (%)
13.12.98	4 pm	22	50	21	50	22	49
14.12.98	7 am	38	47	35	54	34	44
14.12.98	11.55 am	37	46	35	53	33	50
14.12.98	3.30 pm	38	44	35	53	33	49
15.12.98	7 am	38	40	36	53	34	46
15.12.98	11.50 am	38	39	35	53	33	44
15.12.98	2.20 pm	38	39	35	53	33	44
16.12.98	6.55 am	38	37	35	53	34	44
16.12.98	11.50 am	38	37	35	53	34	41
16.12.98	4.30 pm	39	36	35	53	33	39

and the relative humidity by 3%. Experiment 2 reveals a dramatic difference between the two frames: in the frame with the ventilating holes the relative humidity rose by 40 % to 95%, in the closed frame it increased by 6% to only 56%. In neither frame was there a significant change in temperature. Experiment 3 demonstrates that the number of holes has an influence both on the change in temperature and the change in relative humidity. It should be noted that in the frame without holes the temperature rose as expected but the relative humidity increased by only 3%.

We conclude that exhibition and transportation frames for the Dead Sea Scrolls should be constructed completely closed to avoid biological damage and changes in the dimensions of the parchment with the risk of danger to the text[2, 3, 4].

MATERIALS AND EQUIPMENT USED:

- Polycarbonate plates with UV filter
- Cardboard, neutral pH
- Linen, washed and boiled, of pH 8.0
- Acrylic tape, neutral pH, J-LAR, Pemacel
- Polygal (inert)
- Stabil tex, Tetex, Swiss Silk, Zürich
- Thermometer with hygrometer, Crecer Corporation, Tokyo, Japan
- Electric kiln, Adam Mandel

SUMMARIES

Exhibition and Transportation of the Dead Sea Scrolls

Experiments were performed in order to determine the effect of the surroundings on frames with or without ventilation holes, first in a room without climate control, second in a place with relative humidity of up to 100% and third in surroundings of temperature 40°C. It is concluded that exhibition and transportation frames for the Dead Sea Scrolls should be completely closed in order to avoid a change in the dimensions of the parchment.

Exposition et transport des Manuscrits de la Mer Morte

Des expériences ont été faites dans le but de déterminer l'influence du climat environnant sur le parchemin contenu dans des caisses avec ou sans trou d'aération, ces caisses ont été placées tout d'abord dans une pièce non équipée d'air conditionné, puis dans un endroit où le taux d'humidité relative allait jusqu'à 100% et enfin dans un environnement où la température atteignait 40°C. En conclusion on constate que les Manuscrits de la Mer Morte ne devraient être transportés que dans des caisses absolument closes afin d'éviter toute altération des dimensions du parchemin.

Zu Ausstellung und Transport der Rollen vom Toten Meer

Es wurden Untersuchungen durchgeführt mit dem Ziel, die Beeinflussung des Klimas in Kästen mit und ohne Lüftungsöffnungen durch das Umgebungsklima festzustellen, dieses einmal ohne Konditionierung, sodann mit erhöhter Luftfeuchtigkeit bis zu 100%, und schließlich bei erhöhter Temperatur bis zu 40°C. Als Ergebnis wird festgestellt, daß Schau- und Transportkästen für die zur Rede stehenden Objekte dicht geschlossen sein müssen, um Dimensionsveränderungen des Pergaments zu vermeiden.

REFERENCES

1. Boyd-Alkalay, E., & L. Libman: *The conservation of the Dead Sea scrolls in the laboratories of the Israel Antiquities Authority in Jerusalem.* Restaurator 18 (1997): 92–101.
2. Owen, A., & R. Danzing: *History and treatment of the papyrus collection at the Brooklyn Museum.* The Book and Paper Group Annual 12 (1993): 1–12.
3. Hamburg, D.,: *Laboratory of Conservation.* Washington, D.C.: The Library of Congress (unpublished).
4. Stanley, T.: Papyrus storage at Princeton University. The book and Paper Group Annual 13 (1994): 1–14

Esther Boyd-Alkalay
Lena Libman
Israel Antiquities Authority
Jerusalem
Israel

Restaurator, 2000, 25–40
Printed in Germany · All rights reserved

RESTAURATOR
ISSN 0034-5806

Fungi in Archives and Libraries

A Literary Survey

by MATTIAS NITTÉRUS

INTRODUCTION

Biodeterioration of archive and library materials is commonly caused by fungi. The control of fungi means not only suppressing and supervision of active growth, but also an active and conscientious reduction of the total spore amount since these are the reproductive bodies, characteristic for fungi and equipped by nature for surviving under extreme conditions by an almost a fortress-type of structure.

FUNGI

Fungi are specialised micro-organisms which differ from the plant kingdom by the lack of chlorophyll and consequently cannot utilize energy directly from sunlight. The terms 'mould' and 'mildew' are often used by both laymen and biologists to describe these microfungi. Fungi are heterotrophic organisms, i.e. they are unable to synthesize organic compounds from inorganic compounds and therefore need these as their main source of carbon. A majority of the fungi are saprophytes, meaning that they decompose organic substances of plant or animal origin, giving rise to fermentative processes.

Fungi exhibit different kinds of structures, vegetative and reproductive. The principle vegetative unit, the hyphae, is a mono- or multicellular, threadlike filament. The shape and size of these hyphae varies in different groups of fungi, 1.5–12 µm in diameter and from a few up to 100 µm in length[1]. Hyphae can collectively be referred to as the mycelium. Hyphae can be either continuous tubes or divided by septa (walls) into individual cells, arranged in an end-to-end order. These septa are however not entirely closed, single or several openings forming a multi-perforate structure allow protoplasmic streaming[2].

The reproductive unit in fungi is primarily represented by the spore. Spores may be uni- or pluricellular, of many different colours and shapes, depending on

Restaurator 21: 25–40 © 2000 Saur, Munich etc.

the species and growth conditions etc. In size, spores vary from 5 to 20 µm in diameter[3]. The simplest relationship of the spore to the hyphae is by splitting of the cell wall or septum to form cells that behave as spores (*oidia*). Another simple relationship occurs when spores are formed inside ordinary hyphal cells (chlamydospores and arthrospores). Spores can be pinched off at the base of protrusions, directly arising from hyphal cells, a process known as "budding" (blastospores). A more complex arrangement occurs when spores not arise directly from the hyphae, but from special stalks or branches borne by the hyphae (conidiophores). These stalks/branches are usually erect and the spores are produced at their tips as chains, heads or singly.

Spores are the results of either asexual or sexual reproduction. Asexual spore formation is often quick and profuse, making possible rapid dissemination of the fungus during favorable conditions. The resistance of these spores towards drying, radiation and other adverse factors is however restricted. Sexual spore formation is a considerably more complex process, and would be too lengthy to discuss here, but these spores are believed to be far more resistant since they mature more slowly and are able to develop several sturdy outer layers (usually up to three)[4]. Both asexually and sexually produced spores can, if environmental conditions do not allow immediate germination, go into a state of dormancy, stasis, with a hold-over function, in which the water contents of the spore is lowered, and the metabolism inactivated but reversible[3]. These hold-over, or resting spores can tide the organism over periods unfavorable to vegetative growth. In nature, this is the way fungi survive winter or periods of dry weather[5].

The quicker loss of viability of asexually produced spores is believed to depend on their lack of such complex, sometimes hydrophobic, protective outer layers, and lower water contents characterizing the sexual spores. Ascospores of many species (e.g. Chaetomium sp.), show increased resistance towards desiccation, high temperature and even the action of chemicals (cf. Ref. 4 p. 29, p. 717).

The sexual spores are the carriers of the genetic variation, important for the survival of the species, the asexual spores are merely produced to spread and disseminate a certain strain of fungus during favorable conditions. One might say that the sexual spores carry data of the conditions prevailing during its formation and recombining the genetic material to overcome and adapt to future conditions, they are prepared to tide the organism through unfavorable periods, and start the lifecycle anew, as soon as environmental conditions permit. The resistant sexual spores are produced in smaller amounts than the asexual ones[6].

When dormancy of a spore is broken through activation, germination starts with the formation of a germ tube. Long, branching, threadlike structures, hyphae, develop from these germ tubes, eventually forming a complex mycelium[7].

Aspergillus sp. and Penicillium sp. are examples of ascomycetes with *catenulate* (chain-like) spore formation in the imperfect, asexual state. Trichoderma sp. produce spores in conglomerate heads. Spores can be formed in sac-like structures, *asci*, which in turn can be borne inside an enclosing, protective structure known as perithecium. Chaetomium globosum is an example of a fungus producing ascospores, enclosed in a perithecium covered with "hairs" (*setae*)[8].

When sporulation begins, the mature spores are very easily separated from their fruiting bodies, and due to their low weight, spreading and distribution can take place by a minute current of air. Spores can remain dispersed in air for very long time, are easily spread and therefore ubiquitous on our planet. They are not only a potential risk to paper artifacts, as being propagules to new colonies, they may also impose a potential health-hazard to humans causing mycoses, mycoallergies and mycotoxicoses. These diseases include invasions of the skin, lungs, eyes, brain etc[2,9]. Several of the pathogenic fungi belong to the Fungi Imperfecti, or to the yeast-like fungi. Aspergillus fumigatus is a reputed pathogenic fungus with a growth optimum at 37–42°C (mesophilic), and may cause aspergillosis; fungal invasion of the lungs, inner ear etc. Aspergillosis is a severe disease, even lethal, mainly in individuals with immune system malfunctions. Frequent inhaling of spores may evoke allergic reactions; mycoallergies[10]. Certain fungi produce violently poisonous and carcinogenic mycotoxins, (e.g. aflatoxin by Aspergillus flavus), which if ingested may prove lethal (mycotoxicosis).

If spores are allergenic in viable state, these properties will most certainly be maintained even in killed spores[11]. However, the risks are not to be either overrated or neglected; by using protective clothing and spore-safe dust masks covering nose and mouth, and always handling infested material in powerful fume hoods etc., the risks are greatly diminished. Hands may be unprotected, unless minor wounds or eczema are present. Thorough washing with soap and water after handling clears the major part of the fungal debris. Individuals with lowered lung function or immune system malfunction should never handle infested material. Any conservator dealing with fungal infested objects will stress the importance of reducing the spore-amount levels in air by carefully vacuum cleaning the objects objects (HEPA, or water-filters), scrupulously maintaining clean work, storage areas and material.

FUNGAL GROWTH REQUIREMENTS

Humidity

The single most important factor governing fungal growth is the presence of water. It has been common practice to recommend various humidity levels to avoid

fungal bloom. However, these relative humidity levels, e.g., below 75%[12], 65–70%[13], 70%[14], 50–60%[15, 16] cannot be considered completely safe since fungal growth has been reported although RH levels were maintained at, or below, supposedly non-favorable levels[17, 18]. Other authors[3, 19] stress the importance of considering the amount of available water held within such hygroscopic materials such as paper, wood and textiles. This availability, or activity, of water (aW), naturally depends on the amount of humidity in the surrounding air (RH). The relationship between aW and RH at equilibrium can be expressed as:

$$\text{R.H. } (\%) = \text{aW} \times 100$$

that is: an aW of 0,65 corresponds to an RH of 65%. aW is defined as *the ratio of the vapour pressure of water over the material to the vapour pressure over water at the same temperature*[20]. A rise/fall in R.H. of the microclimate surrounding the object consequently induces it to gain/lose moisture to restore equilibrium[21]. The availability of water in a substrate expressed as aW, governs the growth of micro-organisms, generally having a tolerance in aW between 1.0 and 0.55[3, 22], the aW being dependent on the hygroscopic capacity of the material which in turn is influenced by several factors, e.g. pH, presence of solutes, oxygen permeability, deterioration level etc. aW values being the most favorable, or optimum, for growth, seems mostly to be above 0.85, very few below 0.70[19]. Fungi, as a part of their survival strategy, are also believed to withstand low aW by producing polyols, e.g. glycerol, working as osmoregulators, water absorbers, thus enabling retention of rather large quantities of water[3].

It is of major importance for the survival of fungi that the regulation of osmotic pressure by the plasma membrane is maintained, as otherwise important intracellular components would start leaking out, causing lysis. Some osmo tolerant fungi are especially adapted to environments with high osmotic pressure/low aW, and maintain their growth even at such harsh conditions[2]. Aspergillus flavus is reported to survive in very severe conditions, seemingly impossible for maintained growth and reproduction[17].

pH

A majority of the microfungi prefer a slightly acidic environment with a pH of 4–6, and by excreted metabolic waste products also able to change the pH of the habitat if not at an optimum, e.g. by production of oxalic acid[1, 2, 12]. The formation of stains due to coloured products in spores, hyphae and excreted metabolites is believed to be pH dependent, with a maximum stain formation at pH 5[23].

Temperature

The effect of temperature on the growth and survival of the fungi is of considerable importance since it dictates the rate of the reactions catalyzed by enzymes. Three cardinal temperatures are usually determined; the minimum, below which no growth occurs; the optimum, when growth is most rapid; and the maximum, when the fungi are starting to get lethally injured through denaturation of enzymes, disruption of membranes etc. The temperature below which no growth occurs is not to be understood as a lethal temperature.

Many fungi will survive periods of at least several months of continuous subzero temperature. Fluctuating freeze-thaw cycles reduce viability, and finally exhaust even dormant spores, though initially activating[3, 22]. High temperatures, such as moist heat (autoclaves) is quickly lethal, but is not relevant to conservation practice since the heat needed to kill the fungi would also be harmful to the treated objects.

Spores and hyphae in mature colonies showing active growth contain considerable amounts of water, and the majority are killed at temperatures below 0° C, and above or close to 40° C1[12]. There are however exceptions and depending on the conditions at which growth of the micro-organism is optimum, they are divided into different groups:

- Thermophilic organisms colonizing habitats of high temperatures >45°C , optimum 55–65°C, having more heat-stable enzymes, more saturated membrane lipids than mesophilic organisms[2].
- Mesophilic organisms colonizing habitats of moderate temperatures, 20–45°C, ordinary room temperature, many of these mesophilic organisms are pathogenic, showing optimum growth at 37°C.
- Psychrophilic organisms are growing at low temperatures, below 15°C (0°C).

Nutrients

Fungi can utilize almost any naturally occurring compound as a source of carbon and energy as long as the availability of water is sustained. Other elements required are: oxygen, nitrogen, sulphur, potassium, magnesium and various trace elements and to some extent also vitamins. Since the fungi, as earlier mentioned, as a part of their survival strategy can alter their metabolism in order to compensate the lack of some nutritional element, it should be remembered that this often leads to alterations in structure, hue and persistence of produced pigments, reproduction strategies etc.[5, 12, 23].

SANITIZING CONCEPTS IN PAPER CONSERVATION

In reviewing the literature on biodeterioration of paper and especially the methods of dealing with fungal attack on paper collections, the prevailing idea has often been to achieve complete eradication of the biodeteriorative harm, effected by treatment with highly toxic chemicals and/or non-chemical treatment methods with killing properties. Earlier studies often not only recommend treatment of infested objects with toxic chemicals, spraying/fumigation of storage rooms, but also to add these into pastes, glues and mending paper stock[5, 25-28]. Considerations about the effects of these substances on humans or possible deleterious effects to the treated objects are seldom or never made. It has been all too common that conservators have been given advice by researchers from other scientific fields, to use substances or methods originally intended for other applications but similar to conservation problems, e.g. fungal attack. an important role.

The potential dangers of the fungi are the spores, as they are the propagules and threat of new fungal colonies. Any treatment or action in order to combat fungal attack should therefore be directed towards the spores, both by eradication, drastically lowering the total amount by sanitizing and, more important, through preventive measures by careful monitoring of the storage climate. The vegetative parts of fungi, may in contrast to the spores, be considered relatively easy to control. Infested objects often appear severely damaged. By moving the object from growth-favorable conditions, drying and removing the fruiting bodies, visible mycelium and as much as possible of the spores with the aid of scalpels and needles and any vacuum-cleaning device found appropriate, further colonization of fungi will efficiently be inhibited – provided that the object is not returned to the initial climatic conditions.

All work comprising mechanical removal of fungal tissues must be performed in fume-hoods or under exhausters with an effective airflow, and vacuum cleaners or other such devices, fitted with spore-safe HEPA-, or aqueous filters should be used. The careless and untidy habit of "whisking off" fungal debris with the aid of ordinary brushes should be avoided.

Chemical sanitizers

A large number of toxic chemicals have been utilized to sanitize micro-organisms attacking paper collections. A majority of these substances were originally developed for non-conservation use. The substances that have been used and investigated most frequently, are briefly surveyed in the following chapter.

It is difficult to verify if and where any of these substances are still in use. The author is not aware of any national or international standards or regulations, concerning the use of fungicides in archival-, library- or museum depositories.

Fungal sanitizers have been applied as solutions (water or organic solvents), as dusting powders, as pure substance dissolved into adhesives etc., and very often in gas-phase as fumigants. The tendency of these substances, especially chlorinated molecules, to react with the cellulose molecule and other components in the paper (e.g. coatings, fillers, sizing), often makes them harmful to the objects, causing discolouration, embrittlement etc.[1, 12, 29]. Since many of the substances possess low vapour pressures at room temperature (an advantageous quality for some applications), they tend to be retained in the treated material for considerable time, slowly evaporating and thus being a health risk to staff and users. The substances can be divided into the following groups:

Phenolic derivatives

Probably, the most widely used phenolic of this group is Thymol. Thymol, 3-hydroxy-p-cymene, has been used as fungicide in paper conservation practice for almost 60 years, since first recommended for this application by Plenderleith[25]. The application method has most often been through evaporation in specially designed fumigation cabinets, but also as locally applied solution, or as an aerosol treatment.

It is a substance of moderate toxicity, possessing a typical thyme-odour, and is easily absorbed through inhalation, skin contact or accidental ingestion. Several studies have been conducted, trying to evaluate its efficiency as biocide. Results are however contradicting; some studies found it to be a powerful bactericide but inefficient as fungicide, while others report the opposite[11, 12, 15, 30-32].

Thymol is reported to photo-oxidize, yielding discolouration in the paper, which are probably difficult to remove[33]. The retention of Thymol in paper is stated to be prolonged when applied as ethanol solution[34].

Some of the other phenolics used or investigated as potential sanitizers are:

- Pentachlorophenol (PCP)[35]
- p-Chloro-m-chresol (CMC)[36]
- Orthophenylphenol (OPP)[35]
- n-Phenylsalicylanilide[26]
- *Preventol, Dowicide*[1, 11]
- *Shirlan*[37]

All these substances have more or less pronounced antifungal action, but also high to acute toxicity in mammals. PCP and OPP are both reported to accelerate ageing in treated objects[1].

Formaldehyde

Methylaldehyde; Methanal; CH_2O. A 37% water solution of the gas; trade names 'Formol', 'Formalin', has been used world-wide as biocide. It is a powerful chemosterilizer, acting both fungicidally and sporicidally at relatively low concentrations, 1–5% v/v.[21, 38]. Due to its toxicity and highly irritating effect on mucous membranes, the use is now restricted[1]. The highly detrimental effect to proteins and substances consisting largely thereof, (e.g. leather, parchment, hide glue), is known[1, 39]. Despite its drawbacks it was used on a very large scale in the treatment of approximately 8.1 million books and newspaper files, following the fire disaster in the Russian Academy of Sciences, St. Petersburg[40].

Quaternary ammonium compounds

Also known as "quats", this large group of surface-active substances is widely used as both detergents and disinfectants. The disinfectant action is believed to occur in the cellular membranes, which upon treatment lose structural organization and integrity, initiating leakage of intracellular components, (e.g. K^+, $PO4^{3-}$), in many instances the same effects caused by alcohols, phenolics and esters of benzoic acid *Parabens*[9, 21, 41, 42].

Quats are hazardous substances, some even highly toxic and might have a detrimental effect on the immune system[43]. Although frequently recommended in various biocidal applications, they are incompatible with anionic detergents and cations (e.g. Ca^{2+}, Mg^{2+}), which reduce the activity level considerably[1]. The retention of quats and their effects on the physical properties and ageing characteristics of paper has been investigated by Strzelczyk and Rozanski[36].

Ethylene oxide

Oxiran, Anprolene, C_2H_4O. It is a colourless, explosive and toxic gas of high reactive and penetrating power. Originally introduced as an insecticide in 1928, it was first applied in museum fumigation in 1933[44]. It has been widely used as a powerful sterilant, mixed with CO_2 or "Freons" for reduction of explosion risks. Sanitizing potency of EtO has been investigated in several studies[1, 39, 40, 45, 46], and

its possible age accelerating effects on paper have been studied by Hofenk de Graaf[47]. Due to its cancinogenic properties it is now considered an obsolete sanitizer in paper conservation practice. Moreover, it has been shown that material fumigated with EtO is more susceptible to microbial attack[35]. The reason for this phenomenon is not fully known, but in the case of parchment and leather, EtO is believed to react with proteins in the substrate, forming protective micro-encapsulations of fungal spores[30, 37]. Florian[3] claims that ethylene glycol, formed as a by-product during ethylene oxide fumigation, serves as an activator to spores contaminating the object in post-treatment storage. As early recognized, a certain amount of humidity is essential in achieving efficient biocidal effect, as dry materials, fungal spores etc., are largely unaffected by EtO[21, 48].

Other poisonous agents

Naturally, a large number of other chemical sanitizers have been investigated and/or used in various applications, e.g. in the pulp and paper industry, and consequently also in paper conservation during the 20th century, all having more or less pronounced antifungal action, but often hazardous or toxic to humans and detrimental to treated objects.

- Sodium hypochlorite[21, 37]
- Mercury salts[37, 49]
- Organotins[37, 42]
- Benzoic esters[31]
- *Parabens*[9, 42]
- Sulfuryl fluoride[39]
- *Vikane*

Other methods having been sporadically used and investigated include sanitizing/control substances of biological origin, many however now produced synthetically.

Antibiotics

Antibiotics are produced in micro-organisms during growth to repress growth/competition of other species. Substances such as Streptomycin, Nystatin etc., have been used on stone objects and mural paintings to control growth of fungi and bacteria[1]. As to the use of antibiotics in paper conservation however, no scientific reports has according to available information been published.

Enzyme inhibition

Since fungi require nutrients in order to grow and reproduce, the organism uses specific enzymes to degrade the substrate into smaller molecules, e.g. the conversion of cellulose into glucose by cellulolytic enzymes; the cellulase-complex. Studies have been performed on methods of inhibiting this important fungal metabolism, e.g. by the use of the vitamins K[50, 51]. The argument in favor of enzyme-inhibition methods is primarily the exceptionally specific action of these inhibitors. They react only with a corresponding enzyme, and are not active towards the material in the treated object. The enzymes are inactivated almost immediately after addition of the inhibitor. Furthermore, the inhibitors are readily soluble in water, forming colourless solutions.

Inhibitors are considered safe and harmless to humans, and valuable information can be taken from their application in other conservation techniques[52].

Non-chemical sanitizers

Several non-chemical treatment methods have to date been investigated with the intention of being able to control or eradicate fungal growth in paper: deep-freezing, irradiation (e.g. gamma-rays, UV), controlled atmospheres etc. Irradiation methods have achieved considerable attention, and been extensively studied[35, 47, 53-60].

UV

UV-radiation has been found effective against fungi in active growth phase, with a maximum activity at wavelengths varying between 230–275 nm[1]. UV-sources are in common use world-wide to achieve superficial decontamination; laboratory table-tops, utensils etc. The use of UV as sanitizer in paper conservation is however restricted due to a rapid speed-up in ageing/depolymerization processes of the cellulose. UV-lamps are frequently used to detect an active fungal growth in objects since it emits a fluorescent light upon exposure to UV-rays, in contrast to inactive tissue[12].

Gamma radiation

Gamma rays are, together with X-ray and far UV-radiation, different types of high energy electromagnetic irradiation. The nature of the gamma rays enables

them to penetrate deep into the treated materials. Since gamma rays show powerful biocidal action, it is used to sterilize laboratory and hospital utensils. It is relatively simple to use (portable Cobalt-60 apparatus are available), the process is quick and leaves no hazardous residues. There are however considerable drawbacks connected with gamma irradiation which makes its use restricted in paper conservation. By repeated treatments, a cumulative depolymerization of the cellulose occurs, resulting in several ageing characteristics: lowered folding endurance and tear resistance, increased yellowing, general embrittlement[53, 56, 57]. Moreover, since fungi and bacteria require higher irradiation doses to reach required lethal effect, the need of applying doses varying between 5–18 kGy, have been reported[39, 58]. This can be compared with doses of approximately 500 Gy, sufficient to kill larvae and prevent emergence of adult insects[1]. Several other studies specifically focusing on gamma irradiation of paper artifacts have been performed[24].

Other sanitizing methods comprising irradiation, although seldom utilized in paper conservation, are beta-rays and microwaves.

Deep-freezing

The drastic reduction of temperature below the freezing point of water, considerably slows down cellular processes in many micro-organisms. Vegetative parts of most fungi are killed or forced to a standstill at temperatures below 5°C, but spores remain viable even at very low temperatures. Certain fungi have the ability to produce intracellular "antifreeze", enabling them to withstand and even continue growth below 0°C[20]. The most effective way of achieving cell damage is reported to be by rapid freezing of affected objects (more than 1 degree/second), which also yields higher amounts of small intracellular crystals, less harmful to materials than large-crystal formation in slowly frozen objects (less than 1 degree/minute). Not so much is however known on the effects of freezing man-made objects, such as paper, and considerations about the possibilities of alterations/interactions taking place in the paper/coatings/fillers, must be made as this may prove to make the treated papers less resistant to fungal attack in the future[39].

Controlled atmospheres

By using non-toxic inert gases, such as CO_2 and N_2, the treatment of insect infestations in paper collections has showed some success[46]. In diluting the air and re-

ducing the available oxygen, these inert gases work as asphyxiants. The use of controlled atmospheres in treating fungal infestations seems to be an ideal method and has consequently been the focus of some investigations[39, 61–64]. Results indicate that vegetative growth can be stopped, but since fungi strategically respond to alterations in their environment, they adopt to the treatment by considerably lowering their metabolism, going into a state of dormancy, – stasis –, meaning that growth is only inhibited as long as conditions are maintained, but viability of the reproductive units, the spores, is maintained, perhaps even elevated.

Craig[30] claims a 60% CO_2 concentration to be effective, not encouraging stasis. No scientific research available to the author of this study does however support this statement.

Conclusion

Taking into account all aspects, the factor of highest importance in the control of fungi is the control of humidity, keeping it at levels not exceeding 50–55% R.H. and temperatures at 15/18° C. Of same importance is maintaining a good air circulation to prevent formation of still and cold air pockets, producing local dampness[3, 19, 64].

Storage areas and collections can never become free from fungal propagules, unless sterilized. And even if such a sterile condition could be achieved, recontamination would occur as soon as the storage area was opened and the material handled. Therefore such preventive measures as climatic control, keeping spore-contamination levels as low as possible by avoiding dust forming processes and techniques, frequent and thorough maintenance and cleaning of work and storage areas are of fundamental importance. Sanitizing using chemical or physical means include the risk that such direct measures spread a false feeling of security, making the attitude towards preventive techniques less aware. Sterilization, as being the ultimate state of sanitation, is of no interest in conservation practice and artifact maintenance since recontamination occurs as soon as the object is returned to storage.

Summaries

Fungi in Archives and Libraries. A Literary Survey

After a short introduction into the structure of fungi and the conditions for their growth, the means suggested by conservators and microbiologists to cope with the problem of fungal infestation in libraries and archives are discussed: toxic chemicals, radiation, deep freezing, inert gases. Climatic control is emphasized to be the only reliable means, safe as well for the objects as for humans.

La moisissure dans les archives et les bibliothèques. Une enquête littéraire

Après une brève introduction sur la structure et le développement de la moisissure on discutera des moyens suggérés par les conservateurs de musées et les microbiologistes pour se défendre contre la mycose fongique dans les bibliothèques et les archives : substances chimiques toxiques, irradiation, congélation, gaz inertes. Le contrôle du climat de l'environnement s'avère être le seul moyen fiable, inoffensif tant pour les objets que pour l'être humain.

Schimmel in Archiven und Bibliotheken. Ein Überblick über die Aussagen in der Fachliteratur

Nach einer kurzen Einführung in den Bau und die Lebensbedingungen von Schimmelpilzen werden die Mittel diskutiert, die von Konservatoren und Mikrobiologen zur Bekämpfung von Schimmelbefall in Bibliotheken und Archiven vorgeschlagen werden: giftige chemische Substanzen, Bestrahlung, Tiefgefrieren, Inertgas. Die Schaffung von klimatischen Bedingungen, bei denen Schimmel nicht wachsen kann, wird als das einzig zuverlässige Mittel herausgestellt, unschädlich sowohl für die Objekte als auch für den Menschen.

References

1. Caneva, G., M.P. Nugari & O. Salvadori: *Biology in the conservation of works of art.* Rome: ICCROM 1991.
2. *Microbiology.* Ed. L.M. Prescott, J.P. Harley & D.A. Klein. Oubuque (Iowa): William C. Brown 1993.
3. Florian, M.L.: *Conidial fungi (mould) activity on artifact materials – a new look at prevention, control and eradication.* ICOM. Committee for Conservation 10th Triennial Meeting, Washington 1993: 868–874.
4. *The Fungal Spore* . Ed. D.J. Weber & W.M. Hess. New York: Wiley Interscience 1976.
5. *Deterioration of materials – causes and preventive techniques.* Ed. G.H. Greathouse & C.J. Wessel New York: Reinhold Publ. 1954.
6. Wächter, O.: *Restaurierung und Erhaltung von Büchern, Archivalien und Graphiken.* Wien: Böhlau 1987.
7. Florian, M.L. : *The role of the conidia in fox spots.* Studies in Conservation 41 (1996): 65–75.
8. Szczepanowska, H.: *Biodeterioration of art objects on paper.* The Paper Conservator 10 (1986): 31–39.
9. Hödl, I.: *Mikroorganismen auf Papier: Prophylaktische Konservierung, Identifizierung, Desinfektion und Restaurierung.* Preprints. IADA 8th International Congress Tübingen 1995: 181–194.

10. Pantke, M., & W. Kerner-Gang: *Hygiene am Arbeitsplatz - Bakterie und Schimmelpilze.* Restauro 94, 1 (1988): 50–58.
11. Haines, J.H., & S.A. Kohler: *An evaluation of ortho-phenylphenol as a fungicidal fumigant for archives and libraries.* J. Am. Inst. Cons. 25 (1986): 49–55.
12. *Mould/Fungi.* Paper Conservation Catalogue 12 (1994). Ed. AIC Book and Paper Group.
13. Thomson, G.: *The Museum Environment.,* London: Butterworth ²1986.
14. Stolow, N.: *Conservation and Exhibitions: Packing,Transport and Storage Considerations.* London: Butterworths 1985.
15. *Bevaringshåndbogen.* Ed. O. Alkaersig, J. Garff & M. Lundbaek. Köpenhamn: Ejlers 1994.
16. Rebrikova, N.L, & N.V. Manturovskaya: *Study of the factors facilitating the loss of viability of microscopic fungi in library and museum collections.* Preprints. ICOM 10th meeting preprints Washington 1993: 887–890.
17. Nyuksha, Yu.P.: *Some special cases of biological deterioration of books.* Restaurator 5 (1983): 177–182.
18. Gallo, F.: *Biological Factors in the Deterioration of Books. Technical Notes.* Rome: ICCROM 1985.
19. Scott, G.: *Moisture, ventilation and mould growth. Preventive conservation practice, theory and research.* Ottawa: International Institute for Conservation of Historic and Artistic Works 1994: 149–153.
20. Allsopp, D., & K.J. Seal: *Introduction to biodeterioration.* London: Arnold 1986.
21. *Principles & Practice of Disinfection, Preservation and Sterilisation.* Ed. A.D. Russel, W.B. & G.A.J. Ayliffe. London: Blackwell 1992.
22. *The Revival of Injured Microbes.* Ed. M.H.E. Andrew & A.D. Russel. The Society for Applied Bacteriology Symposium Series 12. London: Academic Press 1984.
23. Szcepanowska, H., & Ch. M. Lovett: *A study on the removal and prevention of fungal stains on paper.* J. Am. Inst. Cons. 31 (1992): 147–160.
24. *Biodeterioration of cultural property.* Ed. A.J. Koestler. London: Elsevier 1991: 233–344.
25. Plenderleith: H.: *The conservation of prints, drawings and manuscripts.* Oxford: University Press 1937.
26. Langwell, W.H.: *The conservation of books and documents.* London: Pitman 1957.
27. Cunha, G.M.: *Conservation of library materials.* Metuchen: Scarecrow Pr. 1967.
28. Clapp, A: *Curatorial care of works of art on paper.* Oberlin (Ohio): Intermuseum Conservation Association 1974.
29. Wächter, O.: *Restaurierung und Erhaltung von Büchern, Archivalien und Graphiken.* Wien: Böhlau 1987.
30. Craig, R: *Alternative approaches to the treatment of mould biodeterioration - an international problem.* The Paper Conservator 10 (1986): 27–30.
31. Gustafsson,R.A., I.R. Modaresi, G.V. Hampton, R.J. Chepesuik & G.A. Kelley: *Fungicidal efficacy of selected chemicals in thymol cabinets.* J. Am. Ins. Cons. 29 (1990): 153–168.
32. Dersarkissian, M., & M. Goodberry: *Experiments with nontoxic antifungal agents.* Studies in Conservation 25 (1980): 28–36.
33. Daniels, V., & B. Boyd: *The yellowing of thymol in the display of prints.* Studies in Conservation 31 (1986): 156–158.
34. Arney, J.S., & L.B. Pollack: *The retention of organic solvents in paper.* J. Am. Inst. Cons. 19 (1980): 69–74.
35. Valentin, N: *Biodeterioration of library materials. Disinfection methods and new alternatives.* The Paper Conservator 10 (1986): 40–45.

36. Strzelczyk, A.B., & J. Rożański: *The effect of disinfection with quaternary salt solution on paper.* Restaurator 7 (1986): 3–13.
37. Kowalik, R.: *Microbiodeterioration of library materials.* Restaurator 4 (1980): 99–114; 6 (1984): 61–115.
38. Nyuksha, Yu. P., O.A. Gromov & J.V. Pokrovskaja: *Mass Processing of Documents for Fungi Contamination Control.* Preprints. ICOM 9th meeting, preprints Dresden 1990: 478–481.
39. Brokerhof, A.: *Control of fungi and insects in objects and collections.* Amsterdam: Centraal Laboratorium ... 1989
40. *La conservation: une science en évolution; bilans et perspectives.* Actes des troisèmes journées internationales d'études de l'ARSAG Paris 21 au 25 avril 1997: 369.
41. Denyer, S.P.: *Mechanisms of action of biocides.* International Biodeterioration 26 (1990): 89–100.
42. Hugo, W.B.: *Inhibition and destruction of the microbial cell.* London: Academic Press 1971.
43. Johansson, H., & E. Zimerson: *Tox-info handboken; Kemiska ämnens hälso och miljöeffekter.,* Lund: ToxInfo AB 1994.
44. Ballard, M.W., & N. S. Baer: *Ethylene oxide fumigation: Results and risk assessment.* Restaurator 7 (1986): 143–168.
45. Flieder, F., & Duchein: *Livres et documents d'archives: sauvegarde et conservation.* Cahiers Techniques 6, Protection du Patrimoine Culturel. Paris: UNESCO 1983.
46. Agrawal, O.P.: *Recent studies on biodeterioration of cultural property.* Preprint. 2nd International conference on Biodeterioration of Cultural Property Yokohama 1992: 1–6.
47. Hofenk de Graaf, J., & W.S.Th. Roelofs: *Investigation of the long term effects of ethylene oxide and gamma rays on the ageing of paper.* Contributions of the Central Research Laboratory to the field of Conservation and Restoration. Amsterdam: Centraal Laboratorium 1994: 53–64.
48. Borick, P.M.: *Chemical Sterilizers.* Advances in Applied Microbiology 10 (1968): 291–297.
49. *Disinfection.* Ed. Benarde. New York: Dekker 1970.
50. Makes, F.: *Damages of old bookbindings in the Skokloster library.* Nordisk Tidskrift för Bok- och Biblioteksväsen 71 (1984): 56.
51. Pühringer. J., & F. Makes: *Biologisk mögelbekämpning.* Rapport R93 Stockholm: Byggforskningsrådet 1986: 72.
52. Nikolova, D.: *Proteinase inhibitors from vegetables and their application in enzymatic conservation treatments.* Restaurator 14 (1993): 199–216.
53. Pavon Flores, S.C.: *Gamma irradiation as fungicide and its effects on paper.* Bull. A.I.C. 16 (1975–76): 15–44.
54. Bonetti. M. , F. Gallo, G. Magaudda, C. Marconi & M. Montanari: *Essais sur l'utilization des rayons gamma pour la sterilization des materiaux libraires.* Studies in Conservation 24 (1979): 59–68.
55. Horáková, H., & F. Martinek: *Disinfection of archive documents by ionizing radiation.,* Restaurator 6 (1984): 205–216.
56. Butterfield, F.J.: *The potential long-term effects of gamma irradiation on paper.* Studies in Conservation 32 (1987): 181–191.
57. Adamo, A. M. et al: *Effect of gamma rays on pure cellulose paper.* Restaurator 19 (1998): 41–59.
58. Justa, P.: *Gamma radiation as an alternative means for disinfection of archives.* Preprints. 2nd International conference on Biodeterioration of Cultural Property Yokohama 1992: 51–54.
59. Mann, J., W. Wildführ, H. Langguth & E. Teichert: *Gammastrahlen zur Schimmelbekämpfung bei Büchern.* Restauro 98,2 (1992): 114–119.

60. Tomazello, M.G.C., & F.M. Wiendl: *The applicability of gamma radiation to the control of fungi in naturally contaminated paper.* Restaurator 16 (1995): 93–99.
61. Gilberg, M: *The effects of low oxygen atmospheres on museum pests.* Studies in Conservation 36 (1991): 93–98.
62. Valentin, N., M. Lidstrom & F. Preusser: *Microbiological control by low oxygen and low relative humidity environment.* Studies in Conservation 35 (1990): 222–230.
63. Gilberg, M: *Inert Atmosphere Fumigation of Museum Objects.* Studies in Conservation 34 (1989): 80–84.
64. Valentin, N, R. García, O. De Luis & S. Maekawa: *Microbial control in archives, libraries and museums by ventilation systems.* Restaurator 19 (1998): 85–107

Mattias Nittérus
Paperconservator
Rönnbärsgatan 17
59837 Wimmerby
Sweden
e-mail: mattias.nitterus@adb.kontoret.goteborg.se

Restaurator, 2000, 41–54
Printed in Germany · All rights reserved

RESTAURATOR
ISSN 0034-5806

The Effect of Ionizing Gamma Ray Radiation on the Biology of the *Periplaneta Americana*

by G. MAGAUDDA, M. ADAMO, A. PASQUALI & G. ROSSI

INTRODUCTION

While carrying out activities to preserve the cultural heritage, it is not uncommon to come across more or less serious damage caused by various living organisms. Insects, or rather arthropods, and microorganisms are among the most harmful biological damages. This is partially due to the speed with which the damage is done and to its entity, and partially to the subtlety of the attacks carried out against the objects to be preserved by coy or hardly observable microorganisms.

It is well known that for these microorganisms to develop, the environmental conditions (temperature and humidity), and consequently the conditions of materials, must reach and surpass the critical points reported in scientific literature[1]. It is an equally well known and logical fact that objects made out of organic substances, such as wood, paper, vegetable and fibers of animal origin, leather and animal hides, are the most affected by mechanical and enzymatic biodeterioration[2].

The experts for conserving and protecting the cultural heritage preserved in archives, libraries, natural history and ethnological collections use preventive measures to cope with this problem. In fact, it is both preferable and highly effective to control the indirect and environmental causes leading to the development of harmful organisms, and, when it is deemed necessary, to use chemical substances with long-lasting effects as a means of prevention.

Unfortunately, it is often necessary to intervene once the biological attack has begun, and to use disinfecting and/or disinfesting procedures during the reclamation phase. Experts cope with this problem mainly by fumigation that is using the active ingredients of many chemical substances. However, the use of toxic substances, such as ethylene oxide, for fighting biological attack must be limited, not so much for technical and economic, but for health reasons. In fact, these substances can be harmful to persons using them without using adequate precau-

Restaurator 21: 41–54 © 2000 Saur, Munich etc.

tions. In the case of persistent substances they can also be harmful to the persons who frequent the places where treated objects are preserved[3]. Other substances, such as methyl bromide, are banned also for their negative impact on the global climate[4].

Many have felt the pressure of the growing public environmental awareness and have started to consider studying and applying alternative methods instead of chemical substances. Irradiating the objects with ionizing rays is such an alternative.

IONIZING RAYS

Actually, there have been quite a few systematic studies on the effectiveness of ionizing radiation (gamma or X) against paper biodeterioration, some dating back to the early sixties[3,5–10]. As to the technological side of applying those rays further information is to be found where they are already used, i.e. for disinfection of food[11,12], of medical products, of the environment, etc. In the general frame of a project aimed to study the effect of gamma radiation on the material the objects in archives and libraries are made of, i.e. mainly paper, the purpose of this study was to analyze the effects of irradiation on insects which, along with microscopic fungi and other microorganisms, are most damaging to libraries.

Among the insects especially considered to be harmful for the cultural heritage[13] we purposely selected the *Periplaneta americana* as it constitutes a useful biological model to be studied. Together with other polyphagous species pertaining to the Blattoids order which can cohabit with man, it can be found almost throughout the planet[14]. It is erasing paper together with that starch used as sizing agent or as adhesive and it is damaging paper by littering it with its feces (cf. Fig. 1 & 2).

MATERIALS AND METHODS

Description of the organism examined

The experiments were carried out between 1996 and 1998 on a population of *Periplaneta americana*. The insects were kept in plastic boxes housed inside a controlled environment at 27°C with 60% relative humidity and nourished with the food pellets used in research institutes for feeding small rodent mammals; a few apple slices were added to this basic feed, thus also ensuring the adequate tenor of humidity in the plastic breeding boxes.

Fig. 1: Erosion caused by cockroaches on the binding (title label) of a book (Photo: Istituto Centrale per la Patologia del Libro, Roma)

Fig. 2: Corrosions and stains caused by *P. americana* on paper.

The *Periplaneta americana* is an insect which can be found everywhere it meets a favourable climate, i.e. in a climate that also makes men feel comfortable. It is four centimetres long. It undergoes, so to say, a partial metamorphosis during its life cycle, i.e. the various stages of development are separated by a series of molts: usually 11–12[15]; cf. Fig. 3. Although the insect is smaller and incomplete in its larval stage, its appearance is quite similar to the fully developed adult; this is almost the opposite to insects that undergo a complete metamorphosis such as Lepidoptera. The *P. americana* is ovoviviparous and when the offsprings are born, the female ejects the ootheca with the juvenile larvae inside; this form of reproduction is typical for Blattoids. We have counted up to 20–30 eggs inside an ootheca.

Fig. 3: *Periplaneta americana* during various larval stages.

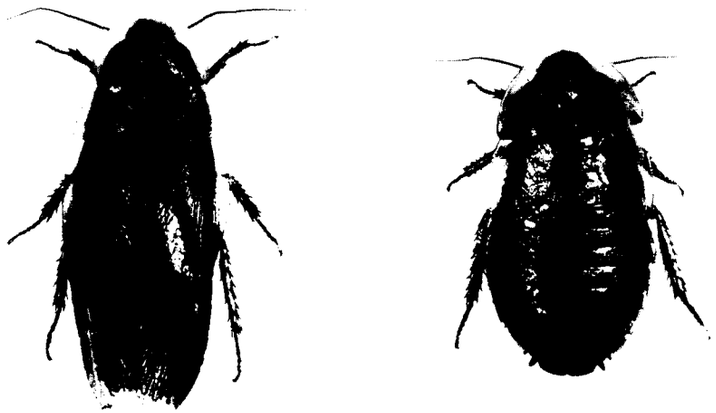

Fig. 4: *Periplaneta americana* adults (right female, left male).

The entire development process, from birth to reproduction, takes about a year under the conditions of our experiment; the adults – males were always the first to complete their metamorphosis – live for a few years feeding on a variety of organic substances. The gestation period lasts 2–3 months.

In the course of our experiments besides adult insects, i.e. those capable of reproduction, we also treated immature insects selected during three distinct larval phases: newly hatched-out ones, those undergoing the early stages of development (≅ 1 cm long: Type A) and those in more advanced stages of growth (≅ 2.5 cm long: Type B).

Since immature specimens do not show clear signs of sexual dimorphism (secondary sexual traits), we did not take into account any gender-related differences for these specimens, what could have been done only by radiosensitivity tests. In their adult form males and females are clearly distinguishable (cf. Fig. 4): males, for instance, have wings all along their abdomen, whereas females, which are generally more thick-bodied than the males, have shorter wings. Both male and female adults have a shinier outside skin (exocuticle) compared to previous larval forms.

Irradiation treatment

The insects were taken out of their breeding boxes for irradiation, counted (no less than 20 specimens) and placed inside paper bags. Radiation treatment was

carried out at room climate: 18°C±2 and 45%±3 RH. We used ENEA's "Calliope" facility at the Casaccia Research Center[16]. It is a pool-type irradiation facility having a cylindrical Co-60 radioisotope source, with a maximum nominal activity of 3.7 x 10^{15} Bq (equivalent to 100,000 Ci). Fricke dosimetry was used to determine the prefixed dosages to use during the experiments according to ASTM D 1671-72 regulations. The range of experimented doses was 0, 15, 20, 25, 50, 100, 150, 200, 300, 500, 1000, and 1500 Gy using a 865Gy/h dose/rate, in which the Gray (Gy) corresponds to the amount of absorbed ionizing energy equal to 1 Joule per kilogram of treated material.

Analysis of the biological effects

Immediately after irradiation, the irradiated insects and their respective controls (non-irradiated specimens) were observed and put back into their breeding boxes, males and females together, but separated according to the absorbed dosage. They were kept in an environmental chamber so they could be analyzed daily over due time.

- Survival was selected as a marker of the effects of irradiation. It was expressed in days and calculated as a lethal dose (LD) for the entire sample population (LD 100). The experimental results were expressed in Dose/Days survival curves. In the case of specimens irradiated with high doses, death occurred after a certain period of time, varying between a few days and a few minutes according to the dose absorbed. During that time, the insects lost their most obvious vital signs (ability to feed and motility), thus losing their ability to damage materials, or they gave way to spasms and tremors.
- The consequences of irradiation on fertility were also studied in the case of adult specimens. This parameter was analyzed observing and recording whether there were any new-borns inside the breeding boxes after the treatment.
- Consequences on the molting of the Types B, A, and new-borns irradiated with doses of up to 150 Gy were also recorded.

RESULTS

Survival after exposure to gamma rays of adult specimens of *P. americana* (expressed in days) is illustrated in Fig. 5. The curve shows a typical response of living beings to radiation treatment, and its non-linear graphic representation

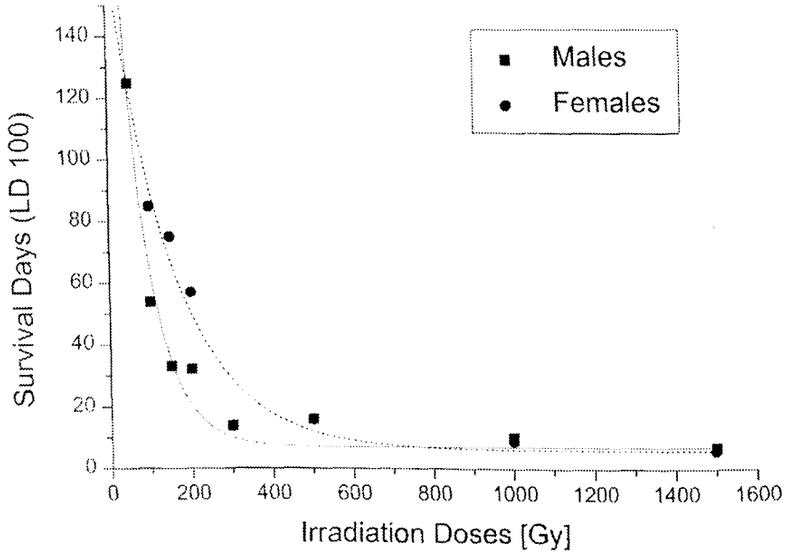

Fig. 5: Survival trend after gamma radiation of *Periplaneta americana* adults according to the doses absorbed.

points to a clear cause/effect ratio, which is particularly drastic in high doses, with a downtrend in the dose range between 300 and 150 Gy. For every experiment we recorded, relating to the absorbed dosage, males had a distinctly lower survival rate than the females. For dosages below 100 Gy the females' survival rate can be up to twice as long as the males'.

The larval stages' (B, A, new-borns) survival to irradiation is illustrated in Fig. 6.

Comparing the trends of the curves relating to the three different stages, only as far as the survival parameter is concerned, it seems that the younger the insect, the more it is sensitive to radiation.

As to molting which, as we have already mentioned, occurs in subsequent stages over a twelve-month period, irradiated larvae at any stage of their growth manage to go from one stage to the next and to reach the adult stage, as long as radiation does not exceed 25 Gy. However, this process appears to be slowed down proportionately with the dosage absorbed (Table 1). As to doses higher than 25 Gy, molting is initially inhibited and, since higher doses lead to the insect's death before it has completed its larval cycle, the molt is entirely overshadowed by the radiation's lethal effect.

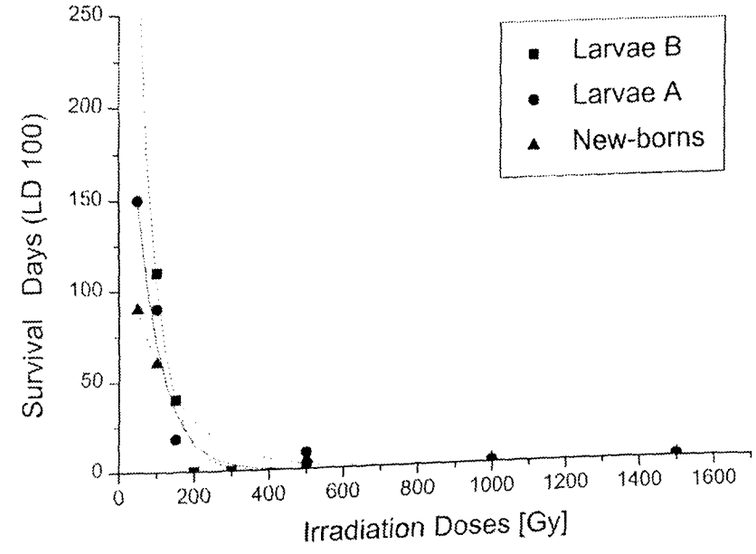

Fig. 6: Survival trend after gamma radiation of the *P. americana* at three different larval stages according to the doses absorbed.

Table 1: Effects of irradiation on the different larval stages expressed according to the time required for the entire larval population to complete their molting cycle. The procedure slows down proportionately with the radiation absorbed.

Irridiation Dose (Gy)	Moulting time (months)		
	Larvae B	Larvae A	New-borns
0	4	5	>9
15	4	5	
20	5	6.5	
25	>9	>9	

The differences between columns in Table 1 clearly depend on the different physiological times required by the various larval stages to reach the stage of full adultness.

According to the doses absorbed, both adults and larval specimens have smaller bodies than non-irradiated specimens (cf. Fig. 7).

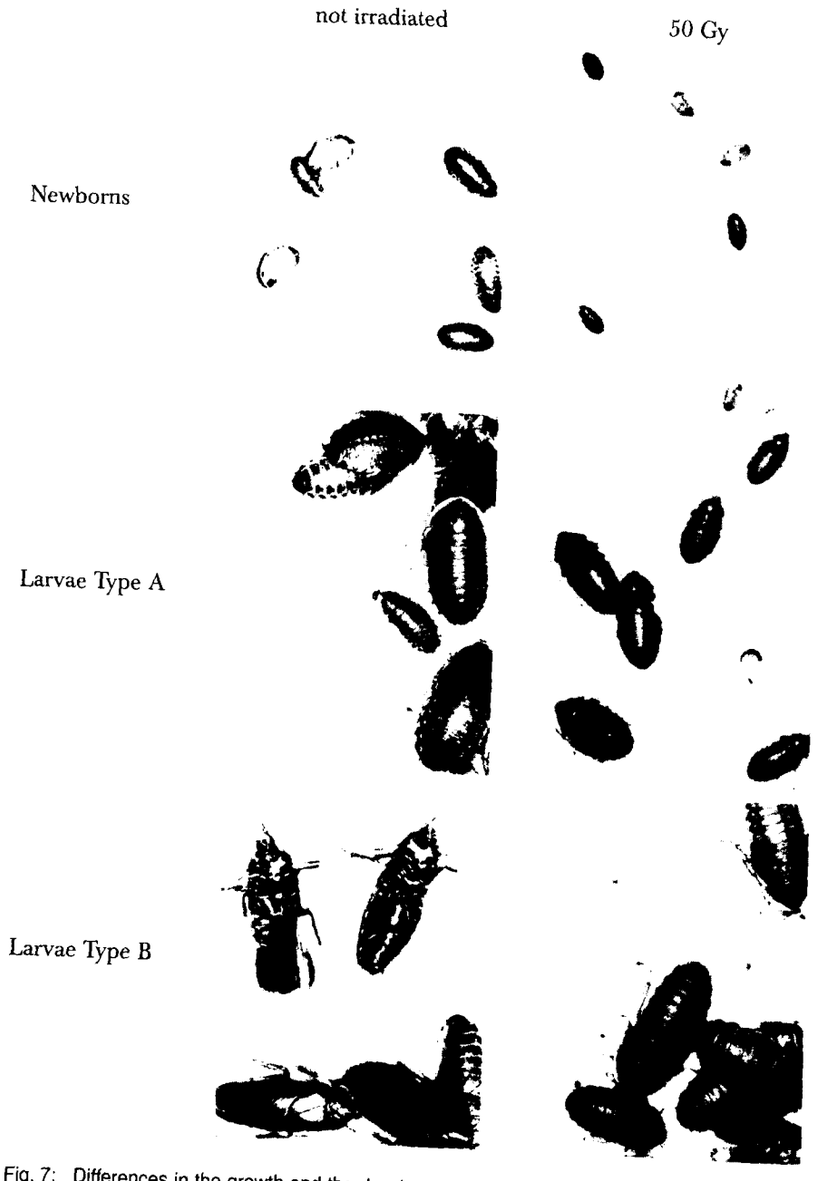

Fig. 7: Differences in the growth and the development of the P. americana after 50 days from irradiation at three different larval stages due to the effects of the gamma ray dosage absorbed (50 Gy).

Fig. 8: Malformation in wing development in a male *P. americana*, which appeared as a consequence of the gamma ray dosage absorbed (25 Gy) in the last larval stage.

Furthermore, somatic malformations (such as the evident ones, affecting the males' wings: cf. Fig. 8) or mechanical difficulties in ejecting the ootheca, which in some cases proved lethal, have been observed.

As to the effects of irradiation on fertility we can state that, unlike non-irradiated specimens, there were no births, even among specimens subjected to the lowest radiations (15, 20 and 25 Gy). This has been further proven because, after having introduced non-irradiated fertile males with radiated females and vice versa in the breeding boxes 18 months after the radiation treatment during which time males and females irradiated had cohabited in the boxes without generating any offspring, the specimens studied after a sufficiently long period of time did not reproduce themselves. The males and females already present in the boxes had been treated with 15, 25, and 25 Gy. In a few cases, in which the female had been exposed to 150 Gy some new larvae were born, but they did not survive more than 15 days (or 50 days when the mother had absorbed 100 Gy). We shall try to interpret this phenomenon during our discussion.

As to very high radiation doses (1000 and 1500 Gy), which lead to the insect's death immediately after radiation or in subsequent days, pregnant females, although extremely weak and often immobile, eject the ootheca from their abdomen with its appendages and with fully-formed but non vital embryos (Fig. 9 & 10).

We wish to recall that, as mentioned under MATERIALS AND METHODS, when non-irradiated insects are born the empty ootheca is simultaneously ejected. Sometimes we found empty oothecae with no newborn larvae, but this phenomenon was also observed in non-irradiated specimens.

Fig. 9: *Periplaneta americana* females immediately after irradiation (1000 Gy) whose internal organs have extroflected along with the recently ejected ootheca.

Fig. 10: Photographic detail of an ootheca in which the embryos can be clearly seen.

DISCUSSION

The results of the effects of irradiation on the survival of *Periplaneta americana* adults and larvae, and on their induced sterility, are clear. Furthermore, the cause/effect ratio of this treatment is significant. In fact, we did not come across

conflicting responses during the repeat tests carried out during our three-year experimentation. Even the different sensitivity to radiation of the male specimens as opposed to the female specimens has been confirmed time and time again.

We believe our discussion should briefly comment on the results of the lethal effects of irradiation on the delicate phases a larval insect undergoes during the molt. The mechanism is similar to that of some hormone-antagonist chemical insecticides which alter the chitin synthesis in young specimens thus interrupting the insect's life cycle[17]. It is difficult to observe this phenomenon, since absorbing high doses of gamma rays leads to the insect's death after a short period, thus not giving time to complete the development between two molts. In the case of very low doses, even if there is enough time for some molting phases, the dose absorbed by the specimens probably does not influence this process.

It is also necessary to recall the great conceptual and practical difference between partially metamorphosing insects, such as the *Periplaneta americana*, and other book damaging insects that undergo complete metamorphosis. The first feed on organic substances and damage books both in their larval stages and as adults. The latter, such as Coleoptera ("wood-worms") and some Lepidoptera, eat away paper and other material they meet in a book almost entirely in their larval stage, whereas adults feed on other substrates or don't feed at all. Consequently, unlike the successful experiments carried out with the "sterile male technique" developed for fighting fruit flies or Olive flies, which also undergo complete metamorphosis[8,19-20], it would be totally useless to try disinfesting books by sterilizing adult Blattoids, Thysanurans (silverfish) or termites without strongly influencing their vitality.

We should like to briefly comment on the premature ejection of the ootheca as a consequence to the radiation absorbed by pregnant females. The ootheca, along with its appendages, takes up a relatively large space in the female's abdomen and it is vital for reproduction. The radiation-induced damage alters the insect's metabolism and affects this fundamental structure. Many organisms in nature, both vegetable and animal, begin reproducing early when they undergo a stressful period; many plants blossom and many insects deposit their eggs. This solves the case of the "extraordinary births", which have hardly any vital signs, born from irradiated females that already contained almost fully-formed embryos when they were subjected to radiation.

Our experience leads us to conclude that to fight the *Periplaneta americana*, the optimal dose of radiation should be no less than 300 Gy. Below this amount, although the surviving animals would be sterile over a limited time, they would also continue to damage materials. This dosage causes practically no damage to paper as measuring the degree of polymerization of cellulose before and after irradiation and before and after artificial ageing prove[21].

Radiation to disinfest the cultural objects can be combined with other methods to fight microorganisms. The technical literature relating to the sensitivity to radiation of microorganisms, especially fungi[3–7], much higher doses for disinfecting paper are given than those necessary for disinfesting it. Doses that were considered as being "high" during our experiments would be necessary for disinfecting paper, thus their effects on insects would be much quicker and more effective.

Finally, as far as transferring the results of this experimentation into practical use is concerned, it is our duty to cautiously remind everyone that our group's activities, along with others, work on many fronts. Our research is concerned both with the effects aspired, i.e. to eliminate biological damage for books and archival documents, and with any undesired side-effects on the materials that constitute this kind of cultural heritage[21].

ACKNOWLEDGMENT

We wish to thank Dr. Stefano Gozzo from Consiglio Nazionale delle Ricerche (CNR) for having kindly provided the insect studied, Mr. Luigi Grisorio from ENEA for supplying his photographic assistance and Dr. Mariagrazia Plossi-Zappalà from Istituto Centrale per la Patologia del Libro (ICPL) for some useful suggestions.

SUMMARIES

The Effect of Ionizing Gamma Ray Radiation on the Biology of the Periplaneta Americana

The project's ultimate goal was to study the feasibility of using ionizing gamma rays to destroy the rodent insects that infest the paper contained in libraries and archives. The experiments dealt with the effects of a wide range of radiation doses on the main biological traits of a population of blattoid insects (of the *Periplaneta americana* species), during the various stages of their life cycle.

The results of tests based on the survival, induced sterility and molting of these insects, all point to the fact that even very low doses of radiation are effective. Furthermore, low doses of radiation are not harmful to the materials that the objects to be reclaimed are made of.

L'effet de l'irradiation ionisante aux Rayons Gamma sur l'organisme de la Periplaneta Americana

L'objectif visé par le projet de recherche consistait à vérifier s'il était possible d'utiliser les rayons Gamma ionisants pour détruire les insectes rongeurs qui attaquent le papier des bibliothèques et

des archives. Les expériences réalisées portaient sur les effets de plusieurs expositions aux rayons de différentes intensités sur les principaux caractères biologiques d'une population d'insectes blattidés (de l'espèce Periplaneta americana) au cours des différents stades de leur vie. Les résultats des analyses réalisées sur la survie, sur la stérilité induite et sur la mue de ces insectes concordent pour confirmer l'efficacité d'irradiations, même à dose très faible, irradiations qui par ailleurs n'ont aucun effet nocif sur les objets à restaurer.

Die Wirkung von ionisierenden Gamma-Strahlen auf den Organismus der Periplaneta Americana

Das Ziel des Forschungsprojektes, über das berichtet wird, war es zu prüfen, ob ionisierende Gamma-Strahlen zur Bekämpfung von papierzerstörenden Schadinsekten in Bibliotheken und Archiven eingesetzt werden können. Es wurde die Wirkung der Strahlung in verschiedener Stärke auf die wesentlichen biologischen Faktoren einer Schabenpopulation (*Periplaneta americana*) während verschiedener Stadien ihres Lebens untersucht.

Als Kriterien der Wirksamkeit galten der Einfluß der Strahlung auf die Überlebensrate, die Häutung und die Fortpflanzungsfähigkeit der Insekten. Alle drei deuten darauf hin, daß bereits sehr geringe Strahlungsdosen die gewünschte Wirkung zeigen: Dosen, die so niedrig sind, daß sie für die bestrahlen Objekte unschädlich sind.

REFERENCES

1. Magaudda, G: *Il biodeterioramento dei beni culturali.* Roma: Borgia & ENEA 1994.
2. Magaudda (Ref.1): 18.
3. Flieder F., R. Ramière, M. Leroy, M. Rakotonirainy & P. Descalle: *Recherches sur l'effet du rayonnement gamma pour la désinfection des papiers.* Actes des Journées internationales d'études de l'ARSAG. Paris 1994: 79–86.
4. Kunstadt, P.: *Radiation disinfestation of woods products.* Radiat. Phys. Chem.52 (1998): 617–623.
5. Belyakova, L.A.: *Gamma-radiation as a means of disinfection of books against spores of mould fungi.* Mikrobiologiya 29 (1960): 762–765.
6. Pavon Flores, S.C.: *Gamma irradiation as fungicide and its effects on paper.* Bull. A.I.C. 16, (1975–76): 15–44.
7. Bonetti. M. , F. Gallo, G. Magaudda, C. Marconi & M. Montanari: *Essais sur l'utilization des rayons gamma pour la sterilization des materiaux libraires.* Studies in Conservation 24 (1979): 59–68.
8. Story, K.O.: *Approaches to pest management in museums.* Washington DC: Smithsonian Institution 1985: 62–69.
9. Chappas, W.J., & N. McCall: *The use of ionizing radiation in disinfestation of archival and manuscript materials.* Biodeterioration 6 (1986): 370–373.
10. Justa, P.: *Gamma radiation as an alternative means for disinfection of archives.* Second Int. Conference of Biodeterioration. Japan 5–8 October 1992.
11. IAEA – *Insect disinfestation of food and agricultural products by irradiation.* Sterile Insect Technique Publication 895 (1991): 174.

12. Tata, A., & M. Adamo: *Stato attuale del processo di ionizzazione delle sostanze alimentari.* Zootecnica Alimentare 1997: 68–83.
13. Szent-Ivany, J. J. H.: *L'identification des insectes nuisible et la manière de les combattre.* La Préservation des Bien Culturels. Rome: ICCROM-UNESCO 1969: 57–74.
14. Magaudda (Ref. 1): 167–173.
15. Grandi, G.: *Istituzioni di entomologia generale.* Bologna: Calderini 1978: 405.
16. Tata, A., S. Giuliani, A. Pasquali, G. Rossi & F. Zarbo: *L'impianto di irraggiamento "Calliope" dell'ENEA.* Energia Nucleare 2 (1995): 76–84.
17. Bolchi Serini, G. *Mezzi chimici alternativi agli insetticidi per la lotta contro insetti dannosi.* Entomologia Urbana e Sanita' Ambientale, ed. G. Domenichini and A.Crovetti. Torino: UTET 1989: 142–153.
18. Steiner, L.F., W.C. Mitchell & A.H. Baumhover: *Progress on fruit-fly control by irradiation sterilization in Hawaii and Marianas islands.* Int. J. Appl. Radiat. Isotope 1962:13, 427.
19. De Murtas, I., U. Cirio, G. Guerrieri & D. Enkerlin: *An experiment to control the mediterranean fruit fly on the island of Procida by the Sterile Insect Technique.* IAEA – Sterile Insect Technique Insect Publication, Proceedings Series 276 (1970): 59–70.
20. Calvitti, M., M. Buttarazzi, C. Govoni & U. Cirio: *Use of induced sterility in adult Trialeurodes vaporariorum (Homoptera Aleyrodidae) treated with gamma radiation.* Journ. Econ. Entom, 1997: 1022–1027.
21. Adamo M., M. Giovannotti, G. Magaudda, M.G. Plossi-Zappalà, F. Rocchetti F. & G.Rossi: *Effects of gamma rays on pure cellulose paper as a model for the study of a treatment of «biological recovery» of biodeteriorated books.* Restaurator19 (1998): 41–59.

G. Magaudda, M. Adamo, A. Pasquali, G. Rossi
ENEA Research Center Casaccia
Via Anguillarese, 301
Santa Maria di Galeria
I-00060 Rome
Italy

Editorial Notice

RESTAURATOR, *International Journal for the Preservation of Library and Archival Material,* presents original papers, as well as reviews and news of interest to scientists, conservators, archivists, and librarians.

Articles for RESTAURATOR are published in English, with Summaries (Abstracts) in French and German. Contributors are particularly asked for linguistic and stylistic accuracy. All articles are linguistically revised by the publisher before publication. Authors alone are responsible for the opinions expressed in their articles.

Manuscripts should be provided in a machine-readable form on a floppy disk if possible; a printed, doubled-spaced copy must accompany the disk. Copy the files onto newly formatted disks and clearly label the journal, author and title, file content, format, software and program version number. Manuscripts must be carefully revised, as alterations are expensive. The paper must be non-absorbent. The author's name must be accompanied by the title, full address, telephone and telefax number (if any) of the workplace or institution. Summaries should be written on a separate page, included with the manuscript; should not exceed 200 words; and should be written in the same language as the articles.

All graphs, drawings, or photographs are to be referred to as figures (abbr: Fig.) and should be numbered in sequence with Arabic numerals. Each figure should be identified with a figure number on the back. Any lines, numbers, or lettering that are to appear in the illustrations should be large enough for the necessary reduction. Line drawings should be drawn or printed with black India ink on white paper and should be about twice the size of the finished blocks. Graphs can be plotted on plain white or blue squared paper; grid lines should be inked in black. In general, photographs should be about 1½ times the size of the final block and must be submitted as mounted glossy enlargements showing good detail and adequate, but not excessive, contrast. Authors should indicate in the text the approximate position of figures.

Italics are used for emphasis, especially for distinguishing titles of books and papers.

References within the text should be indicated by numbers corresponding to those in the list of references. The list should be placed at the end of the paper. For example:

1. Miles, C.: *Wood coatings for display and storage cases.* Studies in Conservation 31 (1986): 114–24.
2. Hon. D. N. S.: *Yellowing of modern papers.* In: Williams, J. C., ed. Preservation of paper and textiles of historic and artistic value II. Advances in Chemistry Series, 193. Washington, DC: American Chemical Society, 1981: 119–42.

Fifty offprints of each article will be sent to the author free of charge.

Editorial Address

Manuscripts and review copies of books should be sent to the editorial office: RESTAURATOR, Dr. Helmut Bansa, Elisabethstraße 23, D-80796 Munich, Germany.

ISBN 3-598-01125-3