Preserving paper: recent advances

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3 Preserving Paper: Recent Advances

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Introduction

The art of preserving is as old as human civilisation itself. In a way it may be said to derive from the instinct of self-preservation common to all animate beings. In spite of everything it seems we want to keep the past alive. For nearly two millennia the preservation of works of art on paper has been practiced in the Far East. Originating first in China at the beginning of the Christian era, conservation techniques and materials quickly spread to Japan and subsequently to other areas. A fifth-century Chinese writer, Chia Ssu-hsieh, raised points in conservation that are familiar to paper conservators today: care in handling objects, choice of correct materials for conservation, correct storage and vigilance against infestation, exposure at correct levels of humidity, and exclusion of sunlight (Wills, 1987).

As a full-grown profession, however, preservation does not have a very long history. Only some 30 years ago paper and book preservation established itself as a true profession in the public domains of education, law, administration and cultural heritage. In the process of professionalization the conservator increasingly made use of science. These days, preservation science is a speciality in its own right in which scientists develop an understanding of why and how archive materials deteriorate and then, in co-operation with conservators, research into methods and materials for arresting that deterioration. In resolving questions, preservation scientists may apply the pure sciences such as chemistry and biology, applied sciences and environmental science as well as several technological areas such as radiography ([AIC-RATS], 2001; Tagle, 1999).

The multitude of preservation research activities, carried out worldwide, indicates an international awareness of the need for scientific tools to tackle the problem of degradation of the world's cultural heritage. Many researchers and research institutes are making efforts to supply conservators and restorers with properly tested means to treat individual artefacts as well as with techniques for mass conservation. Ongoing research is providing new insights into the theoretical background and mechanism of the process of deterioration, allowing a goal-directed approach toward the development of active and passive (preventive) conservation procedures. Some of the recent advances in preservation science, especially those relevant to paper conservation, will be discussed below.

Science or not, we have to keep in mind that the cycle of nature dictates that all things of organic matter must decay. We can only expect to slow down the rate of the deterioration of our paper-based material heritage, the core of our archives.

Paper preservation

At the end of the 20th century a number of trends in preservation are noticeable. Around 1990 governments and institutions alike realized that the paper treasures in archives and libraries were threatened by insidious decay. If nothing were done, before very long large numbers of books, magazines, journals and archival papers would be irreparably damaged, or would even disappear altogether. As a result of this awareness substantial sums of financial resources were allocated to preservation and preventive conservation. In order to make responsible choices risk assessments and damage surveys were developed. One of the results was that paper-based materials after 1850, in particular, were found to age extremely fast due to the high degree of acidity, an effect of essential changes in the paper production process. The scale of the problems was immense thus preservation officers had to develop mass conservation treatment programs. From that moment on the attention shifted from analytical investigation of individual artefacts and individual conservation problems to large-scale national and even international preservation activities (Porck et al., 2000).

At the same time preventive conservation had made its entry into the field, partly for economical reasons. A more critical, hands-off approach evolved, based on a better understanding of conservation problems and of decay mechanisms of objects, as well as on the acknowledgement of the failure of some modern materials that had previously been introduced into the field. The primary question to day is how to prevent damage –

thereby limiting direct intervention on objects to the absolutely necessary (Tagle, 1999).

Since, most advances in preservation knowledge and practice concentrate on the following three categories

- decay: cause and mechanism of degradation
- treatment: active conservation
- storage: passive conservation and damage prevention

To lessen the confusion of tongues it is necessary to define the terms preservation and conservation. In this chapter we follow very broad definitions, which more or less cover the whole field of conservation, in which *preservation* refers to everything, which contributes to the physical well being of the collections, and *conservation* refers to direct physical intervention with the material that is only one part of preservation (MacKenzie, 1996).

Decay

Many causes and mechanism of natural degradation of paper are known to us today. Researchers from the 19th century wondered already why certain papers degraded more than others. Still, there is no generally valid description of the normal, natural aging process of paper. There are so many paper-dependent internal factors, partly as yet unknown, as well as external factors varying with time and place that influence the stability of paper. Nevertheless, the study of paper decay does help us to determine the permanence of paper. As damage surveys and risk assessments are performed more often today, more and more factors of paper degradation become known to us. General tools to ascertain the life expectancy of paper are also of crucial importance, especially during damage surveys. Once we know the life expectancy of a collection, or part of a collection, we can decide what needs our attention first. The need to test paper-based materials, however, can easily conflict with the first rule of preservation, i.e. to prevent damage to the objects. That is why, in most cases, only non-destructive testing methods can be employed. Unfortunately, not many non-destructive testing methods are available for paper.

Non-destructive Paper Testing

Monitoring the degradation of paper is essential for improving our understanding of how paper ages. Until now a suitable instrument for diagnosing the state of paper deterioration has not been found. Existing standardized testing methods often cannot be applied because of the large number of test specimens required.

A research project initiated at the Netherlands Institute for Cultural Heritage (NICH), aims to develop a non-destructive testing method to identify specific chemical compounds in book papers that are precursory to changes in optical and mechanical properties. Recently they experimented with the Solid Phase Micro Extraction (SPME) book-mark method, a well-known sampling technique, for the determination of furfural and acetic acid concentrations in books, a promising class of chemical markers of volatile paper degradation products. With the SPME method volatile compounds can be identified and their concentration levels within the paper quantified in a non-destructive way and as such they become useful as chemical markers to indicate the rate of deterioration. The SPME book-marker looks like a heavy fountain pen and is very easy to handle. So far the results show a good repeatability. For short exposures the uptake of the SPME fibre increases linearly with time, but for exposure times larger than a week the uptake levels off. In order to relate SPME uptakes to concentrations in the paper, the transport mechanism still has to be elucidated (Ligterink et al., 2001).

In PAPYLUM, a research project supported by the European Commission under the Fifth Framework Programme, research institutes from five countries are working together on 'Chemiluminescence.' The construction of an adequate prototype is the primary goal of the project. Due to its extreme sensitivity chemiluminescence (i.e., weak light emitted during a chemical reaction) can well become a non-destructive tool for monitoring the degradation processes at conditions close to those of natural ageing. Since chemiluminescence measurements can easily be performed at temperatures lower than the typical accelerated ageing temperatures, the technique is well worth of an in-depth study. The preliminary results show that the technique may be able to provide the data on stability, usually obtained by long-term accelerated ageing methods, in a much shorter time (Pedersoli et al., 1998; Strlic et al., 2000a, 2000b and 2001).

Artificial Aging of Paper

Artificial or accelerated aging tests are used to determine the permanence (i.e. the rate of the degradation) of paper and to predict the long-term effects of a particular conservation treatment. It speeds the natural aging process of paper by subjecting it to extreme conditions in a climate chamber. Since the 1950s a great variety of artificial aging methods has been developed for paper. The field of application of these methods in the practice of conservation of archival materials has broadened enormously. Nevertheless, research into the reliability of this method is only performed on a limited scale. Today, there are many questions about the actual predictive value of these tests. Differences in opinion still prevail, and there are obvious disagreements as to the conditions under which artificial aging should be performed. Recently, the Koninklijke Bibliotheek (KB), the National Library of the Netherlands, reviewed the various methodologies for accelerated aging and the current discussions (Porck, 2000a).

There is a fundamental problem in the use of accelerated aging. The argument for the use of elevated temperatures in artificial aging relies on the fact that in general a reaction proceeds faster at higher temperatures than at room temperature. This makes it possible to observe its effects more quickly, which in this case is the loss of paper strength. Such artificial aging experiments are sometimes called Arrhenius-tests. The difficulty is that while the Arrhenius-principles apply to the kinetics of chemical transformations, the complex properties of paper that are often registered in accelerated aging (e.g., folding endurance, tear resistance, and paper discoloration) cannot simply and unambiguously be related to its chemical composition. Nonetheless, studies have indicated that, under certain conditions, the rate of the changes of such paper characteristics does relate to the chemical processes that take place during accelerated aging (Baranski et al., 2000; Zou, 1996).

Currently the issue of temperature and relative humidity in artificial aging is still topical. Up to now the aging tests have been done under a variety of temperatures and relative humidities. Because chemical paper degradation reactions vary according to these conditions, the validity of extrapolating results of accelerated aging to natural aging has severe limitations. In this respect the ongoing research at the Smithsonian Center for Materials Research and Education (SCMRE) shows great promise. Their studies are based on the premise that the results of accelerated aging can only serve as a basis for reliable predictions if the accelerated aging method speeds the deterioration of paper without fundamentally changing the process. This means that every individual reaction involved in the decay ought to be accelerated by the same factor and that the relationship between the reaction velocities must be kept constant. It is expected that the results of these studies will form a basis for the formulation of more uniform and relevant accelerated aging protocols (Erhardt et al., 1999).

At the Institute for Standards Research (ISR) an extensive research program is set up that focuses on the development of accelerated aging tests. The program is committed to the development of accelerated tests in three areas: the aging of paper, the effect of light on paper, and the effect of environmental pollutants on paper. Its purpose is to develop testing techniques that will make it possible to develop standards for permanent paper that are based on performance rather than on composition (Arnold, 1996). As part of the ISR research program the Library of Congress (LC) has developed an alternative accelerated aging test for paper. Instead of relying on expensive aging chambers that often lack the desired precision in maintaining preset RH levels at high temperatures, the investigators retain control of moisture at elevated temperatures by sealing paper samples inside airtight glass tubes. These glass tubes have the added advantage of retaining degradation products, just like books do under ambient storage conditions, according to the LC staff. The first data demonstrate that aging within airtight glass tubes simulates natural aging better than aging of paper in loose sheets or in stacks, although in general there is a good similarity between the products of degradation found in naturally aged papers and those aged artificially in the presence of moisture. At present, this test method is being evaluated at the Canadian Conservation Institute (CCI). In the same ISR program the CCI is engaged in a collaborative study to examine the thermal-accelerated aging of paper in sheets and in stacks for some of the ISR papers (Kaminska et al., 1999; Shahani et al., 2000).

A complicating factor is the way in which the paper is exposed to the aging conditions. Confirming earlier studies recent investigations have shown that paper in stacks (i.e., books) ages differently than do single, loose sheets. Some of these studies have shown that under both accelerated and natural aging conditions, the centre of a stack of paper undergoes greater deterioration than do the regions located near the outside. This ‘stack-versus-single-sheet’ phenomenon in the aging of paper is considered of major importance (Brandis et al., 1997; Hanus et al., 1996; Pauk et al., 1996).

Natural Aging of Paper

To compare identical copies of books that, as part of separate collections, have been stored under different conditions and perhaps show different stages of deterioration, would be a logical inquiry in the field of paper aging. The Koninklijke Bibliotheek in collaboration with the TNO (Netherlands Organization for Applied Scientific Research) Institute of Industrial Research got the opportunity to study pairs of books from the collections of the New York Public Library (NYPL) and the Koninklijke Bibliotheek (KB). The conclusion was that the books from the NYPL showed a higher degree of deterioration than the ones held at the KB. This was caused by a higher concentration of the air pollutant sulphur dioxide, in combination with low or fluctuating high and low relative humidity in the NYPL storage rooms (Havermans, 1997; Pauk et al., 1996).

In our search for causes of natural paper aging an historical approach also appears to create possibilities. Recent studies have drawn on historical sources from the mid-nineteenth century that document the inferior quality of Dutch paper at that time. These records can be compared with the findings of present-day examinations of the same material, traced in archival collections. Such comparisons should yield useful indications on the rate of paper decay (Grijn et al, 1996 and 1998; Porck et al., 1996).

To ‘make history’ the ASTM has set up a natural aging project. For the next 100 years, 10 North American institutions in different climates will store volumes of 50 test-paper types and submit monthly and yearly storage condition reports. Throughout this time, specimen pages will be extracted from each site and tested for optical and physical durability (McCray, 1999).

Hydrolytic and Oxidative Paper Degradation

In spite of the campaign for alkaline paper more recent research shows that the acid papermaking process is not the only factor that significantly contributes to the degradation of paper. It is noted that the spontaneous formation of acids in cellulose during aging cannot be overlooked as a cause of paper degradation. Researchers at the Library of Congress investigated the role of acid formation in the process of paper aging. The present findings suggest that weak acids accumulate at a sufficiently high rate to contribute significantly to the increasing acidity in paper as it ages. Also, alkaline papers showed appreciably higher rates of accumulation than did other papers, since the acids formed are immediately neutralized and cannot enter into other reactions or dissipate. It was also shown that these weak acids attach themselves strongly enough to paper and that they are not easily dislodged from the paper matrix, even upon airing.

Because of this tenacity and because they catalyse their own formation, these acids present a constantly escalating source of damage that can be dealt with only through deacidification. Thus, neutral papers cannot remain acid-free for long (Shahani et al., 2000).

Oxidative paper-degradation processes have become the subject of increased attention in preservation science research. This new focus on oxidation is not only confined to specific problems, such as ink corrosion and photodeterioration, but also concerns the study of paper decay in general. Recently, Slovenian researchers turned their attention to the study of oxidative processes in paper. The main factors leading to the deterioration of deacidified paper made from bleached pulp were identified. It is pointed out that autoxidative reactions are accelerated in alkaline media. In addition, certain transition metal ions as well as groups, which are capable of autoxidation, also promote the free radical reactions. Since the oxidative degradation process of cellulose is enhanced in the presence of ferric compounds the efficiency of several possible preventive antioxidants was also tested. The studies clearly demonstrate the protective effect of antioxidants (Kolar, 1997; Kolar et al., 1998 and 2000a; Strlic et al., 1999 and 2001).

Permanent Paper

Permanent paper is the term archivists use to denote the physical substratum for information that shall last for a long time to come (Dahlø, 2000). Impermanence in paper became a problem with industrial papers replacing traditional papers with good properties for long-term storage. An internal threat against the preservation of information was added to all the external threats obliterating our records. That is why the search for and research into the permanence of paper, often based on natural and accelerated aging, is so vital for the preservation community.

It is well known that papers become more acid with age through hydrolysis and formation of acids. It is often presumed that only the acids introduced in the manufacture of paper and those absorbed from the environment are responsible for the deterioration of paper. In this context, the term ‘acid-free’, which in effect equates neutral and alkaline papers, is often used to imply permanence. Nonetheless, alkaline and permanent papers are not the same. Alkaline paper, according to the National Archives and Records Administration (NARA), is considered paper that will last for at least one hundred years under normal use and storage conditions, are groundwood-free with a minimum pH of 7 and an alkaline reserve of 2% or more. Permanent paper, on the other hand, is paper that will last for several hundred years without significant deterioration under normal use and storage conditions. This paper is also groundwood-free with a pH of 7.5 or above, an alkaline reserve of 2% or more, and other strength or performance properties that guarantee the use and retention of records generated on this paper for a maximum period of time (Carlin, 1995). In the 1980s it was thought that by the universal use of alkaline paper for new publications, the acidity problem for the future was solved. In 1996 the *Alkaline Paper Advocate* concluded that her mission had been largely accomplished. Printing and writing papers that are produced for books and documents were then over 80% alkaline in contrast to the early 1980s when it was only 25% (McCrady, 1996).

Today, the ISO catalogue of International Standards lists 202 standards about paper. Three of them are also indexed on 'permanence.' In 1994 the library committee of ISO published ISO 9706 on permanent paper and in 1998 ISO 11108 on archival paper. Where ISO 9706 concentrates on permanence alone, ISO 11108 unites the concepts of permanence and durability. The concepts are defined as follows (Hoel, 1998)

- permanence: the ability to remain chemically and physically stable over long periods of time
- durability: the ability to resist the effects of wear and tear when in use.
- permanent paper: paper which during long-term storage in libraries, archives and other protected environments will undergo little or no change in properties that affect use.
- archival paper: paper of high permanence and high durability

The discussions on permanence in the different ISO committees should be of interest to all conservators as they codify the findings of preservation research.

The International Standard, ISO 9706, which was approved with the cooperation of the paper industry, does not state any limit for lignin content. Instead, the standard has a limit in Kappa number, a figure that expresses the material's sensitivity to oxidation. The logic was; if the paper is sensitive to oxidation, it is likely to get oxidised with time and thus unstable over long time periods. But the dispute remains whether lignin is of harm or not. At present the stand is that as long as it is not proven that lignin is harmless the risk to continue to jeopardise our cultural heritage cannot be taken. What is known today is that lignin is easily oxidised, causes severe colour change and lignin-containing papers discolour other papers in contact with them (Svensson, 1998).

The proposed Canadian Standard for Permanent Paper (CAN/CGSB-9.70-2000) was adopted in 1999 after several years of scientific research, study, and discussion. The communal enterprise of the Canadian Conservation Institute and the Pulp and Paper Research Institute of Canada offers new insight into several factors responsible for the degradation of paper. An important conclusion is that the fibre composition of paper is of minimal importance to its permanence, as long as the paper is buffered with at least 2 % calcium carbonate. This result is scientifically very significant in that it allows paper containing lignin, in contrast to ISO 9706, to be included in those classed as 'permanent.' Yet, it remains to be seen whether or not the new standard will be adopted. If accepted it is likely to have a profound impact on the permanency of archival collections (Bégin et al., 1998 and 1999; Zou et al., 1998).

Ink corrosion

The degradation of paper objects by iron-gall inks, called 'ink corrosion', is a long-known problem among paper conservators. Iron-gall ink is arguably the most important ink in Western history. It became widely used after the late Middle Ages and was widespread in use until the early 20th century. Iron-gall ink is not easily erased and this property made it an obvious choice for record keeping of any sort. International research has cleared a substantial part of its causes. Two ingredients in iron-gall inks are known to cause degradation of paper artefacts: sulphuric acid and iron (II) ions. Sulphuric acid, which is produced as a by-product during the ink formation, catalyses the hydrolysis of cellulose and iron (II) ions, which derive from a basic component of the iron-gall ink, catalyse the oxidation and form radicals.

Dutch scientists from the NICH and the Shell Research and Technology Centre applied scanning electron microscopy (SEM) and X-ray fluorescence analysis techniques to study the presence of iron and sulphuric acid outside the inked areas. They discovered that only in certain samples sulphur had moved of the inked areas, and iron had not (Neevel et al., 1999).

Researchers from the TNO Institute of Industrial Research and the Shell Research and Technology Centre studied the effects of iron-gall inks on the emission of volatile organic compounds (VOCs) from paper artefacts. The findings indicate that the presence of iron in the ink appears to stimulate certain paper degradation processes, namely acid-catalysed hydrolysis and dehydration. The harmful effects of some of the released VOCs have been discussed in relation to the conservation of ink-corroded paper (Feber et al., 2000; Havermans et al., 1999 and 2000; Penders et al., 2000).

Paper discolorations

Local yellow or brown discolorations of paper, often referred to as 'foxing stains', have been the subject of several investigation. However, preservation science research has not yet reached a consensus on the cause of this phenomenon. Several factors presumably are involved in their harmful effect on paper-based materials.

At the Russian State Library researchers found a positive correlation between foxing formation and

- paper production
- duration of light exposure
- dusting and storage condition
- presence of iron(III) in the centre of the stain after dyeing

Further investigations with ultraviolet rays (UV) revealed that foxing stains show heavy fluorescence at an early stage and that luminescence decreases as the colour intensity increases. No fungal or other microbe cells were observed during microscopic analysis. Thus foxing is chemical process, which still has to be researched further, and not a result from microbiological activities (Rebrikova et al., 2000).

In a joint project Parisian scientists applied two non-invasive techniques, fluorescence and Fourier Transform Infrared Spectrometry (FTIR), to identify the chemicals in foxed papers from the seventeenth to the twentieth centuries. Although fluorescence appeared to produce little chemical information, the researchers maintained that the quantitative measurement of fluorescence would be of significant interest if fluorogenic compounds were the precursors of the brown stains. FTIR provided more insight into the chemical characteristics of the foxing stains than did fluorescence (Choicy et al., 1997).

The phenomenon of discoloration that takes place at the border between wet and dry parts in paper materials, has been known since the mid-1930s. This wet/dry interface process, as it is called, is the subject of recent and current investigations into the underlying degradation mechanism. At the NICH, a variety of solvents were used to study the formation of brown lines on filter paper at the wet/dry interface. Also the effects on aging and the conservation treatments of washing and bleaching with sodium borohydride, were studied. In additional studies on the nature of the brown-coloured oxidation compounds formed at the wet/dry interface, the use of analytical tools has been evaluated (Dupont, 1996a; Dupont, 1996b).

Air Pollutants

Where temperature, relative humidity and light have long been the major concern in preventive conservation, indoor air pollution has now become another recognized actor on the scene. It becomes clear that the outside air quality becomes a growing problem, especially in heavy urbanised areas. Many institutes are currently concerned with paper deterioration induced by carbonyl pollution, i.e. acetic acid, formic acid and formaldehyde, and perform air sampling and/or materials testing experiments. In 1998 the Indoor Air Pollution Working Group (IAP), coordinated by the NICH, was initiated. Next to on-going interlaboratory comparisons and the development of standard operating protocols for acid and aldehyde vapour testing, a database is constructed to collate information on materials that have been deemed 'safe' for short-term and long-term use in proximity to susceptible artefacts (see IAP-website).

Researchers from the CCI reviewed and updated the knowledge on coatings that are often used as a means of passive conservation. It is generally known that direct contact with unsuitable coatings or the emission of harmful volatile compounds from coatings can damage artefacts. A summary of control procedures to prevent damages caused by contaminants as well as the use of different spot tests is published so far (Tétreault, 1999a and 1999b). Others at CCI assessed the potential impact of acid-emissive materials on cellulose-containing materials. Little research has been done on the effect of acetic acid environments on paper-based materials. Acetic acid likely causes hydrolysis of cellulose polymers, but the action of weak acids on cellulose has not been investigated to the same extent as that of strong acids (Dupont et al., 2000).

Rapid aging of poor-quality paper materials, such as acidic mat boards, lignin-containing papers, and file covers are known to affect the aging of higher-quality unbuffered paper that is in contact with or in close proximity to them. Scientists from the Carnegie Mellon Research Institute are studying the migration of degradation products from poor-quality materials into higher-quality papers by determining chemical properties.

Although the problem of air pollutants is commonly acknowledged, the mechanism of deposition and threshold concentrations - in particular, the impact of air pollutants on deacidified paper - is not well understood. Useful information can be expected to emerge from a current research project of the Dutch General State Archives in cooperation with the TNO Institute of Industrial Research. In this study identical archive materials are being stored at two locations, one of which is provided with an installation to filter air pollutants.

Continuous monitoring of environmental conditions such as temperature, humidity, and concentrations of air pollutants, as well as frequent analysis of the quality of the stored material in both storage rooms, will yield useful data over time. The first results prove the effectivity of air filtering (Feber et al., 1998).

A Ph.D. student at the Göteborg University devoted her doctoral thesis to the synergistic effects of air pollutants and climate on the stability of paper. The effect of trace amounts of these pollutants on the degradation of paper was studied as well as the ability of the different mass-deacidification processes to provide protection against further acidification of papers. The investigators concluded that RH plays an important role in the uptake of the air pollutants. Clear synergistic effects were demonstrated in the deposition rate. Deacidification treatments did protect paper against the attack of acid air pollutants, although there were some quantitative differences, neither did it provide an adequate protection from oxidative degradation of the paper (Johansson, 2000).

Treatment

The field of conservation has undergone dramatic changes in the last several decades. At the beginning of the 20th century, when many cultural institutions commenced to establish restoration studios, treatment was generally devoted to aesthetic concerns. The aim of restoration was to return the work to its ‘original’ appearance, often without regard for the long-term preservation of materials, the integrity of authentic components, or malignant effects of aging and wear. Today, conservators of paper materials are expected to have a strong background in chemistry as well as art history in order to interpret, predict and arrest the destruction of paper and applied media. Next to preventive methods the treatment is a way to improve the aesthetic appearance, and the chemical and physical condition of archival materials. Howbeit, restoration of individual works is never the ultimate solution to the degradation problem, it must at all times be combined with collections care procedures such as maintaining proper storage and display environments.

Aqueous Treatments

Aqueous treatments have always been important in paper conservation, and there is an extensive literature on their benefits, especially with respect to the improved appearance of the treated papers. Although it is acknowledged that treatment of paper with water also brings about profound, and often permanent, structural and mechanical changes, less attention has been paid to the characterization and quantification of these influences, particularly with a view to optimising conservation procedures.

In 1997, the Camberwell College of Arts reported on a long-term preservation science project entitled ‘Paper Substrates and Graphic Media.’ The purpose of the project was to investigate the effects of aqueous conservation treatments on the mechanical properties of paper. A preliminary study on the effects of ‘paper washing’ showed several main changes, including a reduction in the elastic modulus and an increase in the extensibility, compared with untreated paper. No significant differences were observed between tensile strength before and after washing. These findings provide a better understanding of the ‘improvement’ that is generally observed by conservators as a consequence of the washing of paper; that is, the changes detected have less to do with an increase in the strength of a sheet than with an increase in its flexibility (Smith, 1997).

Pest Control

The number of nuisance organisms in the world is enormous. A small percentage of them are harmful to human beings and their stored goods. Archival collections can be threatened by a variety of pests. They correspond with several thousands of invertebrate pests like insects and mites, with several dozens of vertebrates like rodents, bats, and birds, and with numerous fungi. Archives have traditionally relied on pesticides for routine pest prevention and response to observed infestation. Pesticides often do not prevent infestation, however. 20 Years ago preservations professionals introduced Integrated Pest Management (IPM), originally developed for the agricultural and urban pest management communities. The IPM method of pest control is the least damaging to collections and staff, and involves preventive measures and regular monitoring. Chemical treatments are avoided except as a last resort (see Teygeler, 2001).

To protect documents from the harmful effects of microbiological damage, the vacuum fumigation system using the gaseous sterilizing agent ethylene oxide (EtO) is considered most effective. Although EtO is a significant health hazard and is actually forbidden in several countries, many institutions still use this system for the sterilization of archival materials. In such sites, strict requirements governing the permissible level of exposure are established. To make a comprehensive comparison of the techniques of EtO sterilization and methods of determination of residual EtO in the material treated, an international project has been set up. The results of the different sterilization equipment and procedures applied were compared using different sorts of test samples. Calculations of the content of residual EtO indicated that the samples determined by one method (CNRS, Paris) contained two to nine times higher levels of EtO than did those determined by another method (Chemical Technological University, Prague). Such discrepancies could be explained by differences in technical procedures and time shifts between the various determinations. Nonetheless, the differences underscore the need for a detailed comparison of different techniques and methods, and indicate that a standardized method for quantitative determination of residual EtO in sterilized materials would be very useful (Hanus et al., 1999).

The treatment of microbiological damage is seriously hampered by the fact that the use of ethylene oxide gas is restricted. Consequently, research to develop suitable and safe alternative fungicides is ongoing. Researchers at the Centre de Recherches sur la Conservation des Documents Graphiques (CRCDG) investigated the disinfecting capacity of beta radiation and microwaves. In addition to the fungicidal effect, the influence of radiation on the physicochemical characteristics of the paper samples was determined. Although beta radiation, in a sufficiently high dose, was found to be effective in attacking the fungi, a strong dose-dependent depolymerisation of the cellulose molecules was observed in all cases. Consequently, beta radiation, like gamma radiation that previous studies had found to produce similar adverse effects, cannot be recommended. A fungicidal effect of the microwaves was also demonstrated; the treatment did not show significant negative side effects on the paper itself. Though the practical limitations of the microwave equipment used do not yet allow the possibility of large-scale treatment, the study has clearly indicated the applicability of microwave treatment (Rakotonirainy et al., 1999).

The antimicrobial properties of essential oils have been known since antiquity. Several researchers from the CRCDG are studying the antifungal activity of these oils. They are seeking to develop ways in which to apply them to prevent fungal growth on cultural properties and in storage areas, as well as ways to treat objects that are already infected. The fungistatic and fungicidal activity of six essential oils (bay, wormseed, citronella, eucalyptus, super lavender, and sage) was examined on several fungal strains, commonly found in archives. The effectiveness of the oils was studied in relation to their composition. All six oils revealed antifungal properties, although the results varied. It is unclear, from the preliminary findings, how practical the use of essential oils will be because of the large concentrations required for disinfection (Rakotonirainy et al., 1998).

To fight insect infestation attention has recently focused on the applicability of natural insecticides. The extract from seeds of the neem tree (*Azadirachta indica*), a tropical evergreen, is one of them. Newly the pesticide Margosan-O, a neem extract in ethanol, was developed. The unique qualities of the neem product have been investigated intensively and have yielded encouraging results. In particular, insecticides containing significant amounts of neem oil do not appear to be harmful to human health. In Australia, the oil of the tea tree (*Melaleuca alternifolia*) has been a time-honoured folk remedy for man and beast. At Macquarie University the antimicrobial activity of a large number of commercial tea tree oils was examined. Results demonstrate the importance of terpinen-4-ol for activity against microbes. The powerful antimicrobial activity of p-cymene, a minor component of tea tree oil, was confirmed. Some microorganisms are highly susceptible to a combination of terpinen-4-ol and p-cymene ([Ad Hoc Panel etc.], n.d.; Gateby et al., in press).

One field researchers looked into since the development of IPM in conservation is the use of extreme temperatures in pest control. Controlled freezing has been applied in various institutions over the past 15 years. Paper that has been heavily damaged by water (e.g. by a flood) can be treated by freeze-drying. It is a popular method to prevent mould explosion. Possible negative influences of this drying procedure have not yet received full attention. Scientists from the Danish Royal Library investigated the effects of freeze-drying on the mechanical strength and aging stability of paper. They found that freeze-drying primarily influences characteristics such as moisture content, folding endurance, and tear strength. It particularly affected the mechanical strength of paper with low initial strength; its effect on paper with high mechanical strength was relatively small. In general, freeze-drying influenced paper more than did air-drying. High-temperature treatment has been proved to be effective in exterminating insects in collection materials. The CCI designed a bag that will allow solar heating of the contents (slightly in excess of 40ºC) in such a way that thermal disinfestation of the bag contents will be achieved. The idea was tested by the Australian War Memorial and proven effective (Antonsson et al., 1996; Björdal, 1998; Carlsen, 1999; Pearce, in press; Strang, in press).

It is possible to control insect infestation by reducing oxygen concentration, a form of modified atmosphere. Oxygen reduction is increasingly regarded as a recommendable alternative to insecticides and pesticides. In 1998, the EU financed an international project called ‘SAVE ART.’ Its purpose is to control pests by reducing the oxygen concentration of the environment through the use of an electromechanical nitrogen generator (VELOXY [VEry Low OXYgen] system). The idea is simple but effective: the oxygen in the air surrounding the object is replaced by nitrogen until a residual concentration of 0.1 to 0.2 percent is reached, at which level all insects will be killed. The real-scale tests showed promising results. Since the project’s inception, 12 VELOXY systems have been assembled and are now operative at several museums, libraries, and archives (Åkerlund, 1998; Åkerlund et al., 1998; Conyers, in press; Gialdi, 1998).

Fumigation chambers have always been used in conservation practice to treat objects infested with pests; however, these chambers are expensive to construct, and not all institutions can afford them. An English company, Rentokil, has developed a reusable and flexible fumigation enclosure, the ‘Rentokil Bubble.’ This portable enclosure is designed for use with methyl bromide, phosphine, or carbon dioxide. For the use of nitrogen, the company designed a different line of fumigation enclosures that have a heat-sealable, aluminised barrier film. These bags are not intended for reuse. Two researchers at the Getty Conservation Institute (GCI) tested the enclosures for nitrogen fumigation. The two sizes were tested for both the oxygen-transmission characteristics of the materials and for the gas-tightness of the enclosure. The tests showed varied results but clearly confirmed the suitability of the bubbles for anoxia treatment. Nonetheless, some practical limitations, especially concerning the size of the units, were detected (Elert et al., 1997).

Ink Corrosion Treatment

The treatment of ink-corroded paper artefacts remains a concern in the field of paper conservation. The effectiveness of treatments and their possible negative long-term side effects are often a reason for particular anxiety.

Scientists from several European countries work together in a framework project to study the effects of various aqueous and non-aqueous ink-corrosion treatments. The two well-known mechanisms leading to depolymerisation of iron-gall ink containing papers are acid hydrolysis and autoxidation.

Therefore, a successful stabilisation treatment of ink corrosion should involve deacidification and addition of appropriate antioxidants. The Slovenian partners in the project studied preventive antioxidants like the chelating agents phytate and gallate, and the peroxide decomposers iodide and rhodanide. The iron chelating agent phytate appears to be a potent stabiliser of iron catalysed degradation. However, some other catalytic metal ions (e.g. copper), which are also present in historical iron-gall inks, remain largely unaffected. With this in mind aqueous and non-aqueous treatments for paper containing a variety of catalytic metal ions are evaluated and the development of new treatments was started. It has been demonstrated that addition of preventive antioxidants (e.g. KI) to the phytate treatment of iron-containing paper samples offered advanced protection of the support material. In the case of copper and manganese containing iron-gall ink, calcium phytate treatment also offers superior protection over deacidification alone. Iron-gall ink corrosion has also become an important research priority at the NICH, the Dutch partner in the framework project. In one research the effectiveness of nine commonly used aqueous treatments was measured. Standard reference papers and original seventeenth- and nineteenth-century iron-gall ink papers were immersed in different treatment solutions. Results of this study indicate that a combined calcium phytate/calcium bicarbonate treatment, as well as a single treatment with calcium bicarbonate, could effectively delay ink corrosion and minor side effects (Kolar et al., 1999, 2001 and in press; Neevel, 2000a and 2000b; Strlic et al., 1999 and in press; Reissland et al., 1999).

Russian scientists developed a procedure on basis of a gelatine preparation to slow down the aggressive influence of iron-gall ink. It works on the principle of albumen paper prints in which gelatine forms durable complexes with heavy metals. The study showed that gelatine paper sizing deactivates the ions of heavy metals. When tests were carried out on historical gelatine sized rag papers, written with iron-gall ink, both deacidification agents magnesium bicarbonate and calcium bicarbonate effectively stabilised the process of ink corrosion. Phytate and the antioxidant KI offered additional protection and effects were cumulative, confirming the findings of their Slovenian colleagues (Kolbe, in press).

Laser Cleaning

The idea of using lasers to clean artefacts has fascinated conservators for two decades. Although the potential has been quite clear, past efforts to apply the technology have been hampered by technical limitations, serviceability, and the cost of laser systems.

Although cleaning of paper is a much discussed subject, due to the damages which may arise from conventional wet or dry cleaning techniques, the research on the use of lasers for cleaning of cellulose-based materials remained scarce until recently.

In 1997 the European Union (EU) announced the LACLEPA project (LAser CLEaning of PAper and PArchment). The participating countries will develop a prototype laser-cleaning system particularly fit for flexible paper and parchment. The method is based on the use of UV pulse lasers, which will ensure preservation of the delicate artefacts by minimizing the absorption volume, the heat-affected zone, and mechanical shock. The first experiments with an ultraviolet excimer pulsed laser at 308 nm looked promising. Objects were chosen the conventional cleaning of which were either difficult or impossible. It was demonstrated that surface contamination could be removed by near ultraviolet-pulsed excimer laser irradiation without destruction of cellulose fibre substrate structures including iron-gall ink scripts, yet a decrease in ISO brightness was noticed. On the other hand later experiments showed different results. The results for excimer laser treatment at 308 nm show that not only the laser fluence but also the age of the artefact strongly affects the chemical conversion threshold. Most substrates older than at least several decades exhibited much higher chemical stability than new model systems. This is a strong indication that the aging status of paper artefact plays a major role in assessing the laser cleaning limits. That means that the laser processing behaviour of model systems can be compared with that of original fibrous artworks to only a very limited extent, and that original artefacts have to be treated rather as individual specimens (Fabre, 2000; Kautek et al., 1998, 1999 and 2001; Müller-Hess et al., 1999; Vergès-Belmin, 2001).

In cooperation with the manufacturer of laser systems, Slovenian scientists attempt to define optimum parameters for cleaning cellulose-based substrates using Nd-YAG laser. The immediate as well as the long-term effects of pulsed lasers operating at three different wavelengths on paper have been studied. A strong immediate cellulose degradation effect after excimer laser treatment at 308 nm was observed accompanied by a decrease in ISO brightness. Laser irradiation at 1064 nm resulted in an increase of the degree of polymerisation due to the formation of inter- and intra-molecular ether bonds. Nd-YAG processing at 532 nm resulted in no detectable chemical changes after the treatment, although long-term resistance appears to be impaired (Kolar et al., 2000b, 2000c and 2000d).

Within the European COST program (Co-operation in the field of Scientific and Technical Research) 37 research institutes from 18 countries signed a Memorandum of Understanding to co-operate in the field of laser research under the project name 'Artwork Conservation by Laser.' The project wants to address challenges in three main directions one of which is Laser Cleaning. Amongst others requirements for mobile laser cleaning systems with respect to safety, parameter regimes and performance are investigated as well as laser beam transmission through optical fibres. One study showed that foxing stains from a 16th century old paper could be removed successfully with a molecular fluorine laser at 157 nm. This laser was far more effective in comparison to other wavelengths and did not leave any yellowish after-effect on the paper. Another study clearly indicated that certain pigments could undergo chemical and crystallographic changes and concomitant colour shifts. Also a database is being created of all conservation laser cleaning systems in Europe Very recently a new EU network started: EULASNET E!2566. This is an umbrella for Laser Technologies, one of the themes being applications in conservation. It aims to create a platform to stimulate research, development and technology transfer dealing with laser technologies and applications. Both the EU programs will end in 2005 (see Eulasnet-website; Salimbeni, 2001)..

Mass Deacidification

It is well documented that acid hydrolysis of cellulose is one of the key factors responsible for the degradation of paper during aging. There are a number of strategies one could employ to prevent, or at least forestall, damage to acidic materials. Most deacidification methods work to retard significantly the natural deterioration of paper by neutralizing present acids and by depositing an alkaline buffer to neutralize future acids. Though deacidification stabilizes paper, it cannot strengthen or reverse any damage that has already occurred. Currently there is no one system of choice. There is a clear interest in the commercial world and consequently a certain level of competition. It is clear from existing information that each of the major institutions safeguarding the paper-based heritage has undertaken detailed and exhaustive analyses of the different processes available demonstrating that their eventual choice was not made lightly (Rhys-Lewis, 2001; Smith, 1999).

Implemented by the Conservation Division of the National Archives the Wei T'o mass-deacidification system has been in operation in Canada for many years. One of the major challenges has been the replacement of the original chlorofluorocarbon (CFC) solvents, consequent to a ban on CFCs since 1996.

One year later a new chemical formula using hydrofluorocarbons (HFCs) was tested. The results of these tests have been fruitful. Inks that had been affected by the previous solvents remained stable in the new solution (Couture, 1999).

The Bibliothèque nationale de France has used a mass-deacidification system adapted from the Canadian Wei T'o process. Research into the effectiveness of this system has produced satisfactory results; however, questions remain about both the amount and the distribution of the alkaline reserve in the paper after treatment. With the assistance of the Research Centre for the Conservation of Graphic Material (CRCDG), the Bibliothèque nationale de France has developed a process to neutralise acids contained in certain types of paper, using a deacidification system, which conforms to conservation standards for national heritage collections. Batches of 100 to 200 volumes are vacuum-treated in an autoclave after freeze-drying followed by immersion in a gaseous solution (Daniel et al., 1999a).

The German federal archives have decided to employ Neschen's 'Bückeburg procedure', the main reason being that it is a water-based procedure conceived specifically for archival records. Single sheets are treated separately, guaranteeing individual and uniform results. At the same time harmful substances are washed out and the fibres regain suppleness. The subsequent addition of glue contributes to the stabilisation of the paper (Hofmann, 2000).

In 2000 the Swiss Federal Archives and the Swiss National Library together set up a plant for paper deacidification. After extensive evaluation it was found that the Papersave process offered by Battelle Engineering was the most suitable. The Swiss plant benefits from improved controls and greater variability of the treatment parameters. This opens up new possibilities for the treatment of vulnerable material from archives. The Swiss plant belongs to the Swiss Confederation and is run privately. First experiences show that the Swiss model is a feasible business undertaking (Nebiker Toebak et al., 2000).

In the Netherlands both the Koninklijke Bibliotheek (KB) and the Dutch State Archives decided on the Bookkeeper system. Since 1998 mass-deacidification of books is an integrated part of the conservation policy of the KB in the Netherlands. The KB conservation laboratory has studied the effectiveness and side effects of different mass-deacidification processes prior to the final decision to apply the Bookkeeper system. The results obtained with the Bookkeeper system so far are satisfactory.

However, as the treatment procedure causes a considerable physical stress on the pages and the book as a whole, books with a deteriorated construction and/or severely weakened paper cannot be treated without the risk of serious damage. In their process of evaluation of alternatives to the AKZO DEZ-method of mass-deacidification, the Dutch State Archives preferred the Bookkeeper-method to the Battelle-method. Although they realised that both techniques had their advantages and disadvantages, they found that the Battelle process left a residue of silicon oil after treatment, that the papers experienced an initial loss of strength directly after treatment (up to 40%), that the printing inks were effected, and that there was no trace of paper strengthening as promised by the Battelle (Porck, 2000b; Steemers, 2000).

Several initiatives to evaluate the effectiveness of mass deacidification were taken since the first and biggest evaluation of the Library of Congress in 1991. Most of them were performed with different and often arbitrarily pre-set conditions, which resulted in many differing conclusions. Although it is very hard to draw a final conclusion, it is not impossible. The following seems to be true for mass-deacidification in general

- mass deacidification does not fulfil the hope that archive managers had pinned on it, i.e. to deacidify the whole collection in a single mighty effort and then to forget about the problem of paper decay
- mass deacidification can actually result in the reduced mechanical strength of treated paper
- frequently mass deacidification provokes slight yellowing of the treated paper
- with any of the existing mass deacidification plants negative side effects can occur, resulting from the fact that books and files are not only made of paper, but also of leather, plastics, inks, dyestuffs, board of very dirty pulp, etc., and from poor handling of the books both in the plant and during transportation to and from the plant
- after accelerated ageing the quality of an acidic paper that has been subjected to a mass deacidification process is better than that of the same paper that has not been treated. This is true even for yellowing

Generally, it can be acknowledged that deacidification is an apt means of fighting the problem of acid catalysed paper decay. Above all, with respect to the tremendous amount of books at risk of decay resulting from acidic paper production, it is the only realistic means (Bansa, 2000).

In Germany a new technology is developed to combine deacidification and restrengthening of paper within one process. The deacidification by impregnation with deacidifiers has already reached a satisfying level, but the combination of both steps at the same time still leads to open questions.

A dissoluble-gel based reinforcing system has been developed to carry out the reinforcement not only on single sheets but also with complete books. An anti-adhesive is added to treat the complete book in a dipping process. The experiments show that substantial strength increase could be obtained. For the deacidification, oxidic nanoparticles, such as magnesium oxide added to the impregnation system are presently investigated (Schmidt et al., 2000).

In all cases preservation officers stress the need for careful selection of the materials to be deacified as well as a strict protocol before, during and after treatment. For example, a Swiss study made clear that the colouring agents used in several early non-photographic copies are sensitive to pH and will behave badly during mass-deacidification (Dobrusskin, 1999).

While most treated papers degrade less rapidly, some results from the accelerated aging experiments, however, show an increased degradation of papers whose pH has been changed from acidic to alkaline using deacidification treatments. This behaviour suggests the importance of degradative mechanisms other than acid hydrolysis like atmospheric oxidation. It has also been observed that some acid papers may be destabilized as a result of deacidification treatment. It is observed that a pronounced stabilization of deacidified paper can be achieved by either a sodium borohydride reduction treatment or by the addition of potassium iodide to the deacidified paper. In addition conservators do not know the possible impact of previous deacidification on the conservation treatment and care of paper artefacts (Anonymous, 2000; Kolar et al., 1999).

Paper Splitting

For the strengthening of deteriorated paper, different techniques are available. One of them is the reinforcement of a plastic foil, another would be the infiltration of polymers which re-establish links between the cellulose fibres by polymerisation, and yet another is the paper splitting process. In this practice a paper with a thickness of only a fraction of one millimetre is separated into a front and backside, in order to glue an exactly fitting, very firm and thin reinforcing paper in between. So far reinforcement of deteriorated papers on a large scale has proved to be problematic.

At the Zentrum für Bucherhaltung in Leipzig both mechanical wet treatment and hand splitting paper activities have been practiced for years.

The paper splitting process is a very popular conservation technique to restore papers heavily affected by ink-corrosion. Some years ago this German centre developed a paper splitting machine. Today this machine is a part of a mass-conservation system for loose sheets of paper. The system uses several consecutive processes, including aqueous washing and deacidification, leaf casting and mechanized paper splitting. Results of independent research into the effectiveness and possible negative side effects of this technique are not yet available; nonetheless, there is a growing worldwide interest in the paper-splitting system. The Bibliothèque nationale de France supported a study on mechanical reinforcement methods for paper that compared thermal gluing with splitting. The investigation, carried out on different types of printed paper, demonstrated that splitting resulted in a larger improvement of the mechanical properties of papers, combined with an unaltered readability of the text, than did gluing. Moreover, the reversibility of the splitting process was also considered satisfactory (Kolbe et al., 2000; Liers et al., 1998; Vilmont et al, 1996; Wächter et al., 1996).

Storage

Until recently little consideration was given to the importance of storage methods and materials, often with the result that further damage was done to the objects. It is now recognised that proper attention to storage plays a major part in a successful (preventive) conservation programme. While proper storage can extend life, slovenly, haphazard, overcrowded conditions soon result in damaged collections. These effects are usually insidious and gradual. Already in the design and planning of the archive building many measures can be taken to influence the storage areas of archives. The next step is to look at how a building functions on the inside. In recent times, the impact of environmental conditions on records format has been studied by a number of archivists and conservators. There are many criteria that can be grouped under the banner of conditions; the most important are temperature, relative humidity, air quality and light. Is the building our first line of defence to withstand the external climate conditions, our second line of defence is the control the internal climate of the building (Ling, 1998).

Climate Conditions

The control of temperature and relative humidity is generally accepted as a means to prevent degradation of collections.

Several guidelines are being developed, but the rationale behind these standards is not always clear. The Canadian Conservation Institute (CCI) looked more closely at the basis of these standards and the costs of achieving them. In cooperation with the Canadian Council of Archives they created new recommendations for both temperature and relative humidity. To address the issue of permissible fluctuations for mixed collections, a range of acceptable levels was adopted to replace the old magic numbers (Michalski, 1999 and 2000).

The control of relative humidity (RH) continues to be an expensive and difficult challenge. In many situations, an attractive option is to control the RH within display cases instead of controlling the entire space. Researchers from the CCI are working on a centralized module supplying filtered and humidity-controlled air to each case through small tubes (typically 6-mm diameter) without return air, relying on compensating leakage from the case. The possibility of using an Internet application to provide remote control of the module and remote monitoring of the units is being investigated.

The Smithsonian Center for Materials Research and Education studied the stiffness, strength, and elasticity of cellulose-containing materials. The measurements contradict the general assumption that these materials are necessarily brittle or stiff at all low RH values. In fact, if very low RH (less than 30 percent) is avoided, important physical properties, as well as chemical reactivity (rate of hydrolysis and cross-linking reactions) are relatively insensitive to RH over a wide range (10 to 15 percent). This represents a much wider range than is generally supposed. Similar results have been found with aged paper, indicating that while paper may become weaker as it ages, its stiffness and response to RH do not change significantly (Erhardt et al., 1995, 1996, 1997 and 1999).

The maintenance of storage conditions to established parameters is the most highly discussed element of storage conditions; proper storage temperature and relative humidity are the subject of continued debate. Most researchers tend to agree that the present norms for all archival materials are too tight and that stability of both temperature and relative humidity is at least of the same importance. Besides, norms for both temperature and relative humidity largely depend on local climate conditions. It is of the utmost importance for keepers of archives to be aware of the diverse standards and differing prerequisites. What is a minimum in one country can be a maximum in others, and may be regarded as an optimum in another.

One should not lose sight of the fact that any standard is nothing more than a set of compromises among the participants (Banks, 1999; Buchmann, 1998; Fröjd et al., 1997; Shahani et al., 1995).

Lighting Technique and Guidelines

In the last decade, conservation scientists have given increased attention to lighting issues, particularly the damaging effects of light on paper artefacts. Two processes are responsible for this damage: photochemical action, (which causes fading, chalking, and loss of strength) and radiant heating (which causes surface cracking and embrittlement).

Standard light levels have been introduced over the past 30 years. Although the intent of such standards is clear, their application to broad ranges of object types has been somewhat arbitrary. Resolving the issue of visibility versus vulnerability of the object has been difficult for the preservation community. The Canadian Conservation Institute has been working with a technical committee of the International Commission on Lighting to develop an improved lighting guide. This guide recommends steps to ensure safe lighting of displays, including the classification of all exhibits according to a four-category scale, determination of the acceptable level of UV radiation, calculation of the annual exposures, and planning for the maximum duration of the display, both for the exhibition and for individual objects (Michalski, 1997).

The Rensselaer Polytechnic Institute examined an innovative lighting technique that promises to reduce rates of light-induced damage without affecting viewing satisfaction. Subjective evaluations of works of art displayed under different lighting conditions were recorded. The study suggests that light concentrated in three spectral bands could provide levels of illumination equal to standard broad-spectrum lighting with substantially reduced levels of damaging incident radiant energy. A tri-band source produced by combining and balancing the outputs of halogen lamps filled with narrow band-pass-filters could allow the display of artefacts for longer periods than is possible with traditional illumination sources (Cuttle, 1998).

Storage Materials

Lately preservation researchers became increasingly aware of the importance of archival storage materials. As a matter of fact, the NARA Research and Testing Laboratory maintains a testing program to ensure that proposed exhibit and storage materials do not cause damage to permanent records. All the tested products are listed on the NARA-website.

One of the new products is MicroChamber. First marketed in 1992, MicroChamber is a lignin-free, sulphur-free, alkaline-pulped, alkaline-reserve, paperboard with an additional element - molecular traps or sieves. Especially the last component, the zeolite molecular traps, makes it possible to deal with both airborne pollutant gases. The Centre de Recherches sur la Conservation des Documents Graphiques (CRCDG) compared the protective quality of MicroChamber with that of other archival papers. The researchers concentrated on two of the most widely used MicroChamber products. The papers contained 10 to 15 percent mineral absorbents (zeolites, calcium carbonate). The results showed that the MicroChamber papers absorbed much more sulphur dioxide than did the permanent papers. Interestingly, the verso and the recto sides of each of the paperboards showed different results. This difference appeared to be connected with the weight and sizing of the papers, rather than with the presence of absorbents (Daniel et al., 1999b).

Researchers at the CRCDG also have studied the effects of polyester film encapsulation. In this storage technique an object is encapsulated under low pressure. It is used to protect paper from harmful environmental factors such as air pollutants, dust, and microorganisms. The benefit of this preventive measure has often been discussed and contradicting experimental results have been reported. After analysing the effects of several accelerated aging tests on the degree of polymerisation (DP) of different kinds of paper, the authors concluded that in the case of acid papers, encapsulation enhances the deterioration process. The rate of degradation of non-acid paper appeared to increase significantly only when such paper aged together with acid paper, especially when the mixed stack had been encapsulated. Additional experiments have shown that interleavage with alkaline or MicroChamber paper could partly circumvent this influence. Depending on the situation, this kind of interleavage should be weighed against a deacidification treatment before encapsulation (Daniel et al., 1998 and 1999c).

Closing remarks

Rightly, research is considered an integral part of preservation policy and management. In the future there will even be a greater need for standards, control tools for storage conditions, selection procedures for reformatting, and conservation treatment priorities.

The evaluation of the reformatting or treatment procedures themselves, combined with the development of these standards and tools, represents a full agenda for preservation science. It also induces scientists from different disciplines to work together. Essential is the respect and co-operation between preservation scientists and conservators. The key words in preservation policy today and tomorrow are interdisciplinary approach, multilateral cooperation and legislation, funding, and education. Because it is only when we work together effectively we can expect progress in conservation.

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