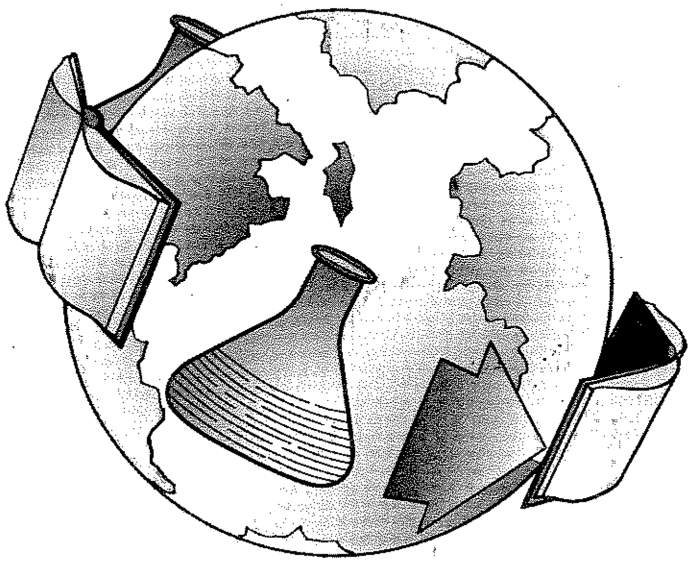
The Commission on Preservation & Access

Mass Deacidification
An Update on Possibilities and Limitations



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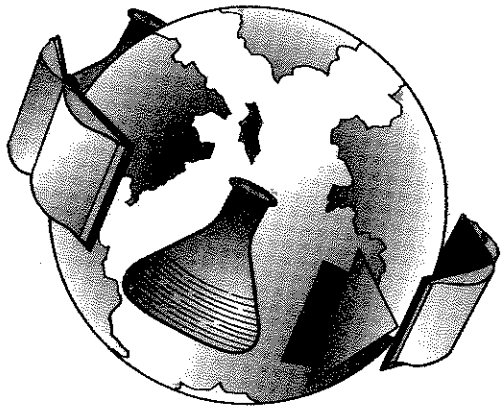

Henk J. Porck
Department of Library Research
Koninklijke Biblioheek/
National Library of the Netherlands
The Hague

European Commission on Preservation and Access,
Amsterdam

Commission on Preservation and Access
Washington

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Auf das man geschrieben hat
Das ist nicht schlimm.
Vielleicht nämlich liest es einer
Und verändert sich.
Schlimm ist nur
Wenn das Papier zerfällt.

Bertolt Brecht
(Gedichte 1933–1938)

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Reactions on this report can be sent to the following address:

Dr. H.J. Porck
Conservation scientist
Department of Library Research
Koninklijke Bibliotheek,
National Library of the Netherlands
P.O. Box 90407
2509 LK The Hague
The Netherlands

Table of contents

Summary

This report is the result of a desk research project aiming to provide an update of the possibilities and limitations of currently available mass deacidification methods. It focuses on the major developments in research and application of the main operational systems.

The *Introduction* outlines the aims and design of the present study, developed in consultation with the European Commission on Preservation and Access.

The next chapters describe the mass deacidification systems included in this study: *Battelle, Bookkeeper, DEZ, FMC,* and *Wei T'o.* For each system a brief history of the development of the technical process is presented, as well as a condensed description of the treatment principle, an overview of available research and test results, indicating the main advantages and disadvantages of the process concerned, and finally an inventory of actual applications of the system.

In addition several other initiatives are described, involving large-scale rather than mass treatment technologies and essentially combining deacidification with strengthening of paper. These initiatives include the *Bückeburg process*, the *Graft-copolymerization process*, the *paper splitting process* and the *Vienna process*.

The data compiled in this report do not allow any conclusions in the sense of a recommendation in favor of any of the techniques described. Instead, in a final section some of the main findings are discussed within the framework of a critical evaluation of the current possibilities and limitations of mass deacidification in general.

The *References* list the literature consulted for this study, publications as well as internal reports. Finally, the *List of contacts* gives the names of representatives of firms and institutions who offered relevant information about the present state of affairs and/or shared their opinions on relevant issues.

Introduction

Aims and set-up

On the basis of a request of the Commission on Preservation and Access (CPA) in July 1995, the Koninklijke Bibliotheek, the National Library of the Netherlands, offered to provide an objective overview of the status of mass deacidification, addressing the major developments. In consultation with the CPA and the European Commission on Preservation and Access (ECPA), the aims and set-up of the study were defined in more detail.

The primary goal was to present a current and essentially worldwide overview of the possibilities and limitations of the use of mass deacidification methods. Intended primarily to support the development of a well-considered preservation policy by librarians and archivists, the study was confined to those mass deacidification systems which have already reached the stage of exploitation, i.e. the Battelle, Bookkeeper, DEZ, FMC, and Wei T'o processes.

Although aqueous deacidification and other conservation techniques can be scaled up considerably, e.g. by moving belt and other mechanical principles (Brinkhus 1988), these methods are in principle excluded from the present study, as are mechanized but principally single-sheet nonaqueous deacidification techniques. An exception was made for those large-scale processes which combine both paper deacidification and paper strengthening as these processes clearly offer an additional benefit for paper that is already weakened and/or brittle, in contrast with the other mass deacidification systems which, aside from the FMC method, only work preventively by slowing down further degradation. The initiatives worth mentioning include the Bückeburg, graft-copolymerization, paper splitting and Vienna processes.

In reviewing the methods, focus is on the practical implications of mass deacidification rather than on technical details of the deacidification process. In particular, the results of test research into the positive and negative effects of the deacidification will be considered. In this respect, the experiences of library and archival institutions in the actual application of mass deacidification in practice are thoroughly addressed.

For each of the main mass deacidification methods sections are included covering *(i)* the historical development of the process technique, *(ii)* the procedure and chemical principles of the treatment, *(iii)* the results of investigations into process efficiency and effectiveness, and *(iv)* the application of the process in the practice of library and archival institutions. The latter section includes information, if available, on health and safety risks, cost estimates, and, for the different institutions involved, quantitative data on the extent and frequency of treatment, priority and selection criteria, overall evaluation of the treated materials, and future planning.

As the optimization of mass deacidification systems represents a continuing process of research efforts and subsequent changes in the treatment ingredients and procedures, data in this report are presented in chronological order. For the sake of objectivity, the mass systems discussed are arranged alphabetically. It should be stressed that this review is not intended as a comparative investigation leading to recommendations in favor of one or another of the systems. The last part of the report is devoted to a critical evaluation of the information collected for this overview.

The present study was set up as a desk-research project, for which various literature sources, such as articles, internal reports and published statements, were used. Both for the purpose of a critical evaluation of the data and to acquire information on the most recent developments, representatives of the different firms and institutions were contacted. By consent their personal communications have been incorporated in the text and their names included in the list of contacts, at the end of this report. To obtain data for a world-wide overview, a general request for information was also sent out. Although negative answers – i.e. no mass deacidification activities are currently being undertaken – have not been included in the text, the respective respondents are mentioned in the list of contacts.

The closing date for the gathering of information for this report was June 15, 1996.

Retrospective view

One of the first applications of paper deacidification is described by O.J. Schierholtz (1936) in his patent for the conservation of wallpaper, using aqueous solutions of calcium bicarbonate. In 1943 W.J. Barrow developed a technique for lamination of paper with cellulose acetate, combined with the deacidification of the paper with aqueous solutions of calcium or magnesium carbonate (Barrow 1965).

Presently, aqueous deacidification is essentially confined to manual conservation treatment. A more or less mechanized variant is the method developed by O. Wächter for the Austrian National Library, in which bookblocks are impregnated with aqueous solutions of deacidification and paper-strengthening agents, followed by freezing and freeze drying of the treated blocks (Wächter 1987a). Another, more extensively mechanized aqueous procedure is the paper splitting process, developed by W. Wächter at the Deutsche Bücherei (Leipzig). In this method sheets of paper are split into two layers and strengthened by insertion of a new central layer of thin paper, containing among other ingredients calcium carbonate as deacidification agent.

An important disadvantage of aqueous treatment is the solubility of certain pigments and adhesives used in books and other documents.

Also the often prolonged drying which is necessary after treatment presents a serious problem in the development of large-scale applications. Pioneering work in addressing this problem was done in the 1960s by R.D. Smith, who developed a nonaqueous deacidification technique based on magnesium methoxide, solubilized in a mixture of methanol and freon compounds, which was applied to paper by spraying (Smith 1970). The use of organic solvents, which can easily be removed by evaporation, has proved to be a sound basis for the further development of mass deacidification techniques such as the Battelle, Bookkeeper, FMC, and Wei T'o processes, which are described in this report in more detail.

Another alternative for aqueous deacidification was the use of gaseous deacidification agents. An early example was the application of the vapor of ammonia for book deacidification in the 1950s in Bavaria, Germany (Smith 1988). The use of cyclohexylamine carbonate (CHC), a volatile organic amine, was developed by W.H. Langwell (1966) for the 'Interleaf Vapor Phase Deacidification' (VPD) process. Another volatile amine, morpholine, has also been investigated for its use in gaseous deacidification and subjected to a limited mass trial. The use of a combination of ammonia and ethylene oxide for large-scale gaseous deacidification has been developed by Book Preservation Associates in cooperation with Information Conservation, Inc. (Cunha 1989, Brandt 1992). Unfortunately all these gaseous deacidification agents pose serious health and environmental hazards.

An important breakthrough in gaseous deacidification, enabling application on a real mass scale, was the development of the diethylzinc (DEZ) process. The DEZ mass deacidification technique, developed by the Library of Congress in the beginning of the 1970s, will be discussed in detail in this report.

The last decade has seen an abundance of published and unpublished research reports and specialist literature on the subject of mass deacidification, including several useful reports and reviews (Cunha 1989, Hon 1989, Schwerdt 1989, Sparks 1990, Neevel 1991, Brandt 1992, Harvey 1993, Mann 1994). In addition, media coverage on the preservation of library and archival materials as a rule emphasizes the important role of mass deacidification in addressing this problem, reflecting a growing interest in the subject on the part of the general public.

Battelle

Development

By order of Die Deutsche Bibliothek (German National Library, Frankfurt/Leipzig), and supported by a grant of DM 17.5 million from the German Bundesministerium für Forschung und Technologie, Battelle Ingenieurtechnik GmbH has since 1987 been investigating different deacidification methods to develop the most suitable system. The first approach, put in operation in a pilot plant in Frankfurt, was a process based on the liquid-phase Wei T'o system, using magnesium methyl carbonate (MMC) as deacidification agent and freon solvents. Though the treatment procedure is similar to that of the Wei T'o system discussed below, several improvements had been realized by the end of 1990, including optimized recycling, fast and homogeneous drying by means of microwaves, and automatization of the process control (Schwerdt 1989).

A change in the solvent and, as a consequence, in the effective deacidification agent, was necessitated by the stricter environmental regulations for the ozone-depleting freon compounds, as laid down in the 1987 Montreal Protocol (Gesetz 1988, Montrealer 1988). The solvent was replaced by hexadimethyl disiloxane (Wittekind 1994a), a colorless organic silicon compound which according to Battelle is not harmful to health and environment. However, hexadimethyl disiloxane is highly flammable. MMC has been replaced by magnesium titanium ethoxide (METE) as effective deacidification agent. METE is a combination of magnesium ethoxide and titanium ethoxide, and according to Battelle capable of both deacidifying and strengthening of paper. Finally a compound was added to diminish the surface tension of the deacidification solution, in order to improve the impregnation in paper. The Battelle pilot plant, constructed in Frankfurt, was moved to the Deutsche Bücherei (Leipzig) and put into operation in 1994.

By using microwave heating equipment, combined with an ingenious control of the radiation process, the drying step could be shortened to approximately 2 hours (Behrens 1993). However, in the course of time, test results showed that the microwave procedure posed many technical and practical problems. For instance, local heat damage of paper caused by metal staples and wire stitches presented a serious problem as these stitches are not uncommon, and especially frequent in German books from the 19th and early 20th century. Consequently, Battelle Ingenieurtechnik decided to replace the microwave equipment by a conventional drying technique, using reduced pressure and heat. This modified installation is currently being constructed in Eschborn, the new location of Battelle since 1993.

Treatment principle

Type of process	Battelle/liquid-phase
Effective agent	Magnesium titanium ethoxide (METE): $Mg(OC_2H_5)_2$ and $Ti(OC_2H_5)_4$
Solvent	Hexadimethyl disiloxane (HMDO;$(CH_3)_3SiOSi(CH_3)_3$)
Procedure	The current deacidification procedure consists of 4 steps: *(i) Predrying:* the paper to be treated is dried for 2 days in vacuum at 60°C, in order to decrease the water content from approximately 6% to 0.5%; the materials are placed in special boxes. *(ii) Impregnation:* the deacidification solution penetrates easily in the paper, and the impregnation and deacidification are completed in only a few minutes; subsequently the deacidification solution is drained. *(iii) Afterdrying:* the remaining deacidification solution in the paper is removed as in the predrying step, by means of vacuum and heat. *(iv) Reconditioning:* after completion of the drying, the documents are reconditioned for 3 weeks in order to regain normal water content in the paper; the storage room is well ventilated in order to diminish the odor of the treated materials. Formerly both drying steps were performed by means of microwaves.
Initial reactions	Magnesium ethoxide and titanium ethoxide hydrolyse easily in the presence of water in the paper. In first instance a metal hydroxide is formed: $Mg(OC_2H_5)_2 + 2\ H_2O \rightarrow Mg(OH)_2 + 2\ C_2H_5OH$ $Ti(OC_2H_5)_4 + 4\ H_2O \rightarrow Ti(OH)_4 + 4\ C_2H_5OH$ The forming of ethanol (C_2H_5OH) is probably the cause of the typical (sweet) odor of the treated paper. Under influence of the environmental air, a second reaction step will form magnesium carbonate ($MgCO_3$) and titanium dioxide (TiO_2).
Deacidification	The magnesium carbonate and the residual metal hydroxides neutralize the acids present in the paper.
Alkaline reserve	The excess of magnesium carbonate in the paper forms the alkaline reserve, protecting the paper against future acidification.

Research results

The first thorough and independent scientific studies of the Battelle process have been performed in the Netherlands. In 1994 the CNC, the National Preservation Office of the Netherlands, reported the results of a pilot study on the effects of the Battelle deacidification method, which indicated a number of advantages and disadvantages (Pauk 1994). The CNC decided to do a more elaborate study on the Battelle method, which was carried out by TNO Center for Paper & Board Research in Delft and the Koninklijke Bibliotheek in The Hague (Deventer 1995, Pauk 1995, Havermans 1996).

The primary aim of the investigations was to obtain a thorough insight into the positive and negative effects of the Battelle deacidification method on books and archival materials. Important aspects were the directly observable effects of the treatment, the homogeneity of the deacidification, and the effect on the permanence of the paper. For permanence, both chemical and physico-mechanical paper characteristics were examined; not only the effects of accelerated (thermal) ageing were investigated, but also the protection offered by the deacidification treatment against the air pollutants sulfur dioxide and nitrogen dioxide.

In general, the Battelle deacidification appeared to result in a positive contribution to the permanence of the paper, both in books and in archival materials. In 84% of the books, and 2 out of 3 archival materials, paper degradation was convincingly inhibited in the *long term*, and there were clear indications that the Battelle treatment protects against the influence of acid air pollutants.

Despite these positive results it was concluded from the research results that the Battelle process suffers from a number of shortcomings which could obstruct a large-scale application. In the first place a large part of the testmaterial (40% of the books and 2 out of 3 archival materials) showed a significant immediate decrease in paper strength as a *direct* result of the deacidification treatment. Moreover, the ageing tests showed that also in the *long term* a considerable part of the tested books (16%) and archival materials (1 out of 3) do not benefit from the Battelle treatment. Secondly, despite the introduced improvements in the treatment procedure, there were still undesired side effects in the deacidified materials, such as discolorations, white deposit, Newton rings, bleeding of inks and dyes, odor and the different 'feel' of the paper. Finally there was no homogeneous distribution of the deacidification agent in books and compact stacks of paper.

There were indications that certain properties of paper, such as porosity and nature of sizing may have an influence upon the effect (positive or negative/no effect) of the Battelle treatment on paper permanence. Further investigation of these paper characteristics is recommended in the research report, also in order to come to a definition of inevitable preselection steps for the Battelle system.

The results of the CNC investigations, as summarized here, are in contradiction with the claims put forward by Battelle on the basis of their own test results (Wittekind 1994a, 1994b). Both the alleged general strengthening, as a direct result of the treatment, and the absence of undesirable side effects appear to be disproved. However, the materials tested in the CNC investigation were treated by Battelle in the summer of 1994, and Battelle has stressed that since then additional improvements have been introduced in the treatment procedure, especially in the drying steps, resulting in the further reduction of side effects and improved homogeneity of the deacidification (Wenzel, pers. comm. 1996).

Last year the modified process was tested by several German libraries and archives. Of the institutions involved, the following responded to a request for information: the Landesarchiv in Berlin (Dettmer, pers. comm. 1996), the Staatsbibliothek zu Berlin (Baron, pers. comm. 1996), the Bibliothek für Bildungsgeschichtliche Forschung in Berlin (Bierwagen, pers. comm. 1996), the Deutsches Museum in München (Berninger, pers. comm. 1996), the Bayerische Staatsbibliothek in München (Trapp, pers. comm. 1996), the Bundesarbeitsgericht in Kassel (Welle, pers. comm. 1996), the Max-Planck-Institut für Europäische Rechtsgeschichte in Frankfurt (Deter, pers. comm. 1996), the Universitätsbibliothek in Mannheim (Leichert, pers. comm. 1996), the Hessisches Staatsarchiv in Darmstadt (Wolf, pers. comm. 1996), the Hessisches Landes- und Hochschulbibliothek in Darmstadt (Staub, pers. comm. 1996) and the Landesbibliothek in Coburg (Erdmann, pers. comm. 1996). Although the investigations are not yet fully completed, the first results of the performed test runs are generally considered encouraging.

Over the last few years the Battelle system has also been tested in Switzerland by the Landesbibliothek (National Library) and the Bundesarchiv (Federal Archives), in cooperation with the Wimmis Pulverfabrik. The results of the tests with regard to the effectiveness of the deacidification and to the occurrence of side effects were promising and met the minimal requirements established in July 1995 (Herren 1994, Herren 1995, Herion, pers. comm. 1996).

Application

The first Battelle installation, put into operation in a library setting, was installed in 1994 in the Deutsche Bücherei (Leipzig). It has been estimated that the number of books to be deacidified in Die Deutsche Bibliothek (German National Library, Frankfurt/Leipzig) is around to 12 million (Lehmann 1992). Although the Battelle installation is intended to deacidify 400,000 books per year, the actual treatment has until January 1996 been limited to approximately 60,000 books, and the system is not yet operating on a continuous basis. Together with technicians from Battelle, work is still in progress to adjust and optimize the treatment procedure. A special problem is the predrying of the books, for which originally microwave equipment has been installed, creating the technical and practical difficulties already mentioned above (Wächter, pers. comm. 1996).

A Battelle installation at present under construction in Eschborn has been set up as a service center for German libraries and archives and will initially have a capacity of 120,000 books per year. The treatment costs will depend on the size and weight of the books, and on the magnitude of the contract with Battelle. For octavo-format books with an average weight of 0.5 kg, costs per book are estimated at DM 15–20, including transport and insurance. The materials to be treated should be packed by the customers themselves in special boxes of metal wire. The sealed boxes are transported to Eschborn for treatment, during which the books remain in the boxes. After the treatment the boxes will be returned. The Battelle center in Eschborn is planning to extend its services to include freeze-drying of water-damaged materials and treatment of biological damage by insects and fungi. Plans to found additional Battelle service centers in Germany are still in a preliminary stage (Behrens, pers. comm. 1996).

Worth mentioning is the initiative of the Landesbibliothek (National Library) and the Bundesarchiv (Federal Archives) in Switzerland to establish a Battelle installation for the deacidification of books and archival materials. On the basis of a survey performed on mass deacidification systems and of comparative testing of the DEZ and FMC processes, it was concluded that the Battelle system offers the best prospects. After a one-year detailed engineering phase, starting in May 1996, plans and cost estimates for the Battelle plant will be submitted to the Swiss Parliament in 1997. Construction is planned for the beginning of 1998, and the plant should be operational at the end of that year (Herion, pers. comm. 1996).

Bookkeeper

Development

The Bookkeeper process was developed in the early 1980s by Richard Spatz, at that time co-worker of Koppers Company Laboratories. When this company cancelled further investigation into the process in 1987, because commercial prospects did not seem promising, Spatz founded a new firm, Preservation Technologies, Inc., and continued the project under the name 'Bookkeeper'. Initially the pilot plant was located in Orville, OH, later in Glenshaw, PA, and since September 1995 in Cranberry, PA. Recently the Dutch company Archimascon (Rotterdam) opened negotiations with Preservation Technologies, Inc., to construct a Bookkeeper plant in the Netherlands (Dorsten, pers. comm. 1996).

The deacidification is based on a liquid-phase process using magnesium oxide (MgO) particles suspended in an organic solvent (perfluoro heptane). In the ongoing process of optimization, the most recent adaptation was made at the end of 1995 when, on the basis of tests performed in cooperation with the Library of Congress, by improving the fluid dynamics of the treatment process, the concentration of magnesium oxide in the suspension could be decreased by 50%, at the same time maintaining a sufficient alkaline reserve. The lower concentration of magnesium oxide appears to reduce the problem of white deposits on the treated paper and covers. Modification of the fluid dynamics and additional reduction of the magnesium oxide particle size also resulted in an improved uniformity of the treatment (Gaydos, pers. comm. 1996, Report 1996).

Research results

The results of the first investigations into the effectiveness of the Bookkeeper system were very promising (Cunha 1989). The pH values of the paper in a series of books, amounting to 4.3–7.5 prior to treatment, could be increased to 7.6–9.0 by the Bookkeeper deacidification. Accelerated ageing tests and folding endurance measurements showed a significant decrease in the rate of paper degradation as a result of the treatment. Standard treatment of approximately 1,000 books over a period of 2 years did not reveal harmful effects on inks and various bookbinding materials, including leather bindings. The evident absence of damaging side effects is connected with the fact that the treatment suspension is free of alcoholic compounds and that predrying is not required.

A Belgian study comparing different mass deacidification techniques recommended the Bookkeeper system as one of the best with respect to the homogeneity of distribution and final values of both pH and alkaline reserve, and the occurrence of side effects on writing and printing inks (Liénardy 1992, 1994).

Treatment principle

Type of process	Bookkeeper/liquid-phase
Effective agent	Magnesium oxide (MgO)
Solvent	Perfluoro heptane
Procedure	Basically there are two procedures. The Bookkeeper I and II deacidification units were developed for the deacidification of loose sheets of paper and books with exceptional dimensions. Bookkeeper III is constructed for the treatment of books in general. All systems are essentially closed circuits and apply mechanical means to produce controlled motion of the treated objects in the deacidification suspension. Through this motion, horizontal in the case of Bookkeeper I and II and vertical with Bookkeeper III, the books or paper stacks fan open, allowing optimal contact of each individual sheet of paper with the treatment suspension. For this purpose special holders have been developed, unto which the books are attached by means of a strong but soft cord, which runs through the gutter region in the middle of the books and fixes the spine to the center of the book holder. Bookkeeper III consists of 4 cylindrical treatment vessels which are operated in sequence and offer a complete treatment of 32 books in 2 hours. The treatment procedure consists of the following steps: *(i) Pretreatment:* the books to be treated are placed in the vertical cylinder where, after a vacuum pretreating step, pressures are equalized and the deacidification suspension is pumped in. *(ii) Impregnation:* the books are gently agitated parallel to the spine of the books for 15–20 minutes in the suspension, after which the suspension is drained and recycled. *(iii) Aftertreatment:* the books are dried for 90 minutes under vacuum, and are subsequently removed from the cylinder to an open room environment for 24 hours, to ensure moisture equilibrium.
Deacidification	The magnesium oxide which is introduced by the treatment adheres to the paper fibers and neutralizes the acids in the paper. In the case of sulfuric acid, the reaction is as follows: $MgO + H_2SO_4 \rightarrow MgSO_4 + H_2O$
Alkaline reserve	The magnesium oxide particles which have not reacted form the alkaline reserve in the treated paper.

In the fall of 1994 a Technical Evaluation Team reported the results of an extensive investigation of the Bookkeeper process performed by order of the Library of Congress as second phase of its 1992 Action Plan. It was concluded that the Bookkeeper system has the potential of meeting the requirements set by the Library for an adequate process. The disadvantages related to heavily coated paper, on which a white deposit was found, and thick books, showing insufficient alkaline reserve in the inner (gutter) margins (Buchanan 1994).

A limited study of the Koninklijke Bibliotheek (National Library of the Netherlands) on a series of books treated with the Bookkeeper process in the summer of 1995 yielded satisfactory results. Accelerated ageing tests and paper strength measurements showed that of 80% of the treated books the useful life was significantly increased. Disadvantageous side effects with respect to synthetic bookbinding materials, odor and discolorations were not observed. The only problem consisted of a white powdery deposit on the paper and covers, especially with coated paper (Pauk 1996).

In 1995 the Library of Congress and Preservation Technologies, Inc. established a joint initiative to improve the Bookkeeper process. By studying the effects of a wide variety of process modifications on a series of disposable test books, significant adjustments could be introduced at the end of 1995, resulting in improved deacidification of the inner margins of book pages and in the minimizing of powdery deposits on book covers and (coated) paper. It was concluded from the test results that the modified Bookkeeper process met the Library's requirement for extending the useful life of books by a minimum of 300% and exceeds the 1.5% alkaline reserve requirement. Moreover, undesirable side effects, such as odor and damage to covers and adhesives, appeared to be absent. The only problem recognized was the incomplete impregnation of heavily coated paper (Report 1996).

Application

As the safety and health risks are minimal, the Bookkeeper system could easily be located in a library or archive building. Moreover, the installation requires little space, has simple process control and does not need highly qualified personnel.

Just like the former pilot plant in Glenshaw, the new, enlarged facility in Cranberry offers the Bookkeeper mass deacidification services at a commercial scale. The Bookkeeper II installation for oversized books has a capacity of approximately 40,000 books per year. The Bookkeeper III installation for regular books has a capacity of 120,000 books per year, the treatment costs amounting to $ 11.75 per book, exclusive of transport (Burd, pers. comm. 1996).

Several US libraries have signed up for the Bookkeeper treatment and offered the following useful information on their experiences. Unless stated otherwise, the items selected for treatment are (heavily) used, acidic but not-yet-brittle books, whereas excluded from treatment are pre-1850 and rare books, documents with many illustrations and/or coated papers and weak bindings, which would not withstand the stress of the treatment. There appears to be a consensus about the results of the treatment, which are considered satisfactory on the basis of measurement of pH and alkaline reserve. Undesirable side effects are generally limited to a powdery deposit on some of the covers and coated papers.

The Case Western University Library (Cleveland) began its use of the Bookkeeper treatment in 1987 and started regular shipments in 1991. To date, approximately 650 books from the general circulating (used) collections have been treated. The library intends to continue to deacidify yearly shipments of books, up to 1,000 a year (Gubkin, pers. comm. 1996).

The Love Library of the University of Nebraska-Lincoln sent a shipment of 350 bound volumes from the 19th and 20th century general collection to Preservation Technologies in 1993. No specific criteria were used for preselection or for exclusion from treatment. Though no further shipments have been sent to Preservation Technologies so far, this will be done again in the future, depending on the budget, as there is clearly confidence in the Bookkeeper system (Walter, pers. comm. 1996).

The University of Notre Dame has been using the mass deacidification services of Preservation Technologies, Inc. since 1993, and approximately 800 volumes (music scores, avant-garde British playwrights printed on cheap paper, and select portions of theology) have been treated so far. The University is presently in the process of negotiating terms of purchase or lease of Bookkeeper treatment equipment, to be installed in its new laboratory, which it plans to use not only for its own collections, but also as a deacidification service site (Jordan, pers. comm. 1996).

Since October 1994, 4,600 volumes from the Northwestern University Library (Evanston) have been treated with Bookkeeper. At present 450 items are being processed per month. Future plans are to continue with the Bookkeeper treatment and gradually increase the monthly shipments (Frieder, pers. comm. 1996).

The Cleveland Public Library started using Bookkeeper for maps and other single sheets of paper in 1994. In 1995 shipment of books was started, and so far 200 books have been treated. Future plans are to continue the current practice with the Bookkeeper service, but not on a real mass scale, and to set up an inhouse spray system using Bookkeeper reagents, primarily for the treatment of large-sized maps and other single sheets (Olszewski, pers. comm. 1996).

After unsatisfactory results of a project with the Committee on Institutional Cooperation (CIC) on the DEZ and FMC processes in 1991, and more encouraging results of two test runs with Bookkeeper in 1992, the Pennsylvania State University Libraries contracted with Preservation Technologies, Inc. in 1995; 163 books have been treated so far. Current plans are to continue with Bookkeeper, but due to financial restrictions the number of books that will be sent for treatment yearly will be limited (Kellerman, pers. comm. 1996).

The Oberlin College Library started to use Bookkeeper in 1995, and so far 4,700 books have been treated. Besides the white dusting on some of the book covers and pages, 20% of the books appeared to be insufficiently deacidified in the gutter, and a few covers were damaged (bubbling, tackiness). The Oberlin College Library will continue to mass deacidify books in the future, as long as funds are available (Schoonmaker, pers. comm. 1996).

Since 1995 the Pittsburgh Theological Seminary Library has had approximately 400 books and archival records treated with Bookkeeper. The material consisted of various documents, pertinent to the historical background of the institution. Aside from pre-1850 books, no other materials were eliminated from treatment. Because of the satisfactory results, unique archival materials have also been processed. Negative effects were limited to a slight stickiness of some synthetic bindings. The library has raised an endowment fund and plans to spend approximately $ 8,000 per year on Bookkeeper treatments (Crocco, pers. comm. 1996).

In June 1995 the Library of Congress entered into a trial contract with Preservation Technologies, Inc. to further optimize the procedure and to treat 72,000 books over a two-year period. The contract was awarded under the terms of the Library's second Mass Conservation Action Plan (1995–1997), approved by the US Congress. The new, expanded facility of Preservation Technologies, Inc. in Cranberry met a number of the Library's contract objectives relating to security, insurance and improved environmental conditions. Up to January 1996, disposable books were treated and tested as part of a joint research plan of the Library and Preservation Technologies. On the basis of the test results, described above, a number of additional modifications were introduced in the treatment. The resulting improvement of the deacidification of the inner margins of book pages strengthened the Library's confidence in the Bookkeeper process, and in the beginning of 1996 a start was made with the treatment of real library books (Report 1996).

Nürnberg variant

In the last few years a variant of the Bookkeeper process has been developed in Germany by the company Libertec Bibliothekendienst GmbH in Nürnberg. An interesting modification has been introduced in the treatment procedure: instead of using an organic fluid to apply the effective agent, magnesium oxide (MgO), to the paper, MgO deposition is mediated by air. The MgO powder is blown in from below the books, which are fanned open by the air current. The duration of the treatment, which determines the amount of MgO applied to the paper, is attuned to the initial pH value and the weight of the book. In a subsequent step, a current of air with a high relative humidity is used to stimulate the absorption of the MgO into the paper. The Libertec installation has a daily capacity of approximately 200 books, with treatment costs per book of DM 15 (Bell, pers. comm. 1996).

Although research data are not yet available in published form, satisfactory test results have recently been reported by the Bayerische Staatsbibliotheek in München (Trapp, pers. comm. 1996).

DEZ

Development

The basis of the diethylzinc (DEZ) mass deacidification method was established by G.B. Kelly and J.C. Williams, co-workers of the Library of Congress, Washington. From estimations in the 1980s, it appeared that a considerable number of books from the Library's collections were in an extremely deteriorated state. Moreover, this number would increase each year with 77,000 books (Johnson 1988). According to the Library of Congress, none of the existing deacidification techniques could be applied on a sufficiently large scale (500,000–1,000,000 books per year). As a consequence, the Library of Congress took the initiative to develop a new and adequate system. A gaseous deacidification agent was considered preferable, and out of the studied organo-metallo compounds, diethylzinc proved to offer the best prospects. Compared with liquid-phase deacidification, gaseous deacidification has the advantage, that many different objects can be treated without the risk of damage to inks, dyes and adhesives.

After successful laboratory testing, the DEZ process was scaled up at the General Electric Space Center, Valley Forge, Pennsylvania (Kelly 1987). Between 1981 and 1986, the system was tested in a pilot plant at the NASA Goddard Space Flight Center. Partly in connection with an accident during a test of the treatment chamber in 1985, related to the very strong chemical reactivity of liquid diethylzinc, NASA withdraw from further investigation and the plant was dismantled in 1986 (Johnson 1988, Sebera, pers. comm. 1996).

The chemical process industry offered a better setting for dealing with these problems, and in 1988 Texas Alkyls (now part of AKZO Chemicals, Inc.) was awarded a contract by the Library of Congress to construct and operate a DEZ pilot plant in Houston, Texas.

In 1990 the Library of Congress invited proposals for mass deacidification of its endangered collections. Three systems participated (DEZ, FMC and Wei T'o), and each performed test-runs on approximately 500 books which were evaluated by the Institute for Paper Science and Technology in Atlanta (Major 1991). Although none of the mass deacidification processes appeared to conform to the technical requirements defined by the Library in every respect, the DEZ system was considered to offer the best prospects, especially with regard to the efficiency of the process and the effectiveness of the deacidification.

Since 1992, the Library of Congress and other institutions in the US and Europe have significantly contributed to the process of further optimization of the DEZ process, by performing and evaluating of testruns. In the sections on research results and applications more detailed information on the results of the investigations and the institutions involved will be presented.

A dramatic turning point in the development of the DEZ process was the decision of AKZO in 1994 to cancel further work on DEZ, due to lack of commercial prospects. In April 1994 the mass deacidification plant in Houston was closed, and AKZO terminated its DEZ license with the US Commerce Department in September 1994. No facilities are presently available to process materials utilizing the DEZ process.

Research results

Initial damage problems in case of synthetic bookbinding materials could be prevented by using spacers between the books, so that there was room left between the bindings during the treatment procedure (Johnson 1988).

The first results of different tests performed by the Library of Congress on various series of books indicated that DEZ treatment achieves a complete and fairly homogeneous neutralization of the acid components in the paper, irrespective of the type and concentration of the acid and the sort of paper and bookbinding material. Accelerated ageing studies have shown that the DEZ treatment of different sorts of paper causes a general and significant decrease in the rate of paper degradation, measured as change in the folding endurance (Sebera 1990).

With a final pH value of no more than 7.0–7.8 in the cold water extract of the treated paper, the DEZ system offers one of the mildest deacidification processes. Even very acidic books ($pH < 3.0$) were neutralized sufficiently by the DEZ process, leaving adequate amounts of alkaline reserve in the paper. This advantage has been attributed to the very fast diffusion and transport of gaseous deacidification agents as compared to deacidification methods using liquid impregnation (Neevel 1991).

The alkaline reserve (1.8–2.5% $CaCO_3$) has proved to be optimal for the different sorts of paper studied, taking into account various factors such as duration of treatment, process costs, effect on permanence, and visible and morphological paper characteristics. The alkaline reserve of the treated books showed a homogeneous distribution from sheet to sheet, with variations restricted to differences between the margins and the centers of the pages, the margins having slightly higher levels.

A disadvantage of the DEZ treatment is that zinc oxide appears to accelerate the photochemical oxidation of cellulose (Kelly 1981, Daniels 1990). This also applies to zinc sulfide, which may be formed by the reaction of zinc oxide with hydrogen sulfide (H_2S), sometimes present as a component of polluted air (Neevel 1991). As the conversion of zinc oxide into zinc carbonate proved to decrease the sensibility of the treated paper to photo-oxidation, the original pilot plant at General Electric applied an after-treatment of the books with

Treatment principle

Type of process	DEZ/gas-phase
Effective agent	Diethylzinc (DEZ;$(C_2H_5)_2Zn$); DEZ is a liquid at room temperature and at normal pressure. In gaseous form, at reduced pressure, it is used for the deacidification process (Sebera 1990).
Procedure	*(i) Preconditioning:* the books are placed on carts, spine down and separated from each other by 10 mm spacers, and driven into the cylindrical steel treatment chamber; preselection is confined to large-format books and strongly coated paper, which need a separate, prolonged treatment; after flushing the chamber with pure nitrogen gas, the books are dried for 20–30 hours at reduced pressure and 40–60°C, to decrease the water content of the paper to approximately 0.4%. *(ii) DEZ treatment:* after evaporation of liquid DEZ, the gaseous DEZ is introduced into the treatment chamber and kept at reduced pressure for 10–12 hours; when the weight of the books, which is continuously registered, stabilizes, the flow of DEZ is stopped, after which the excess of DEZ is removed and recycled. *(iii) Reconditioning:* subsequent to the complete removal of DEZ by means of flushing with dry nitrogen gas and vacuum, water vapor is introduced into the chamber for approximately 6 hours to accomplish the gradual regain of a normal water content in the paper; after return to atmospheric pressure, the chamber is opened and the books are removed.
Deacidification	Gaseous DEZ is very reactive with the strong and weak acids present in paper. In the neutralizing reaction of DEZ with sulfuric acid, zinc sulphate ($ZnSO_4$) and ethane gas (C_2H_6) are formed: $H_2SO_4 + (C_2H_5)_2Zn \rightarrow ZnSO_4 + 2\ C_2H_6$ The zinc sulphate deposits in the paper, while the ethane gas is removed, together with the excess of DEZ in the second step of the treatment procedure.
Alkaline reserve	With the controlled amount of water present in the paper, DEZ forms a controlled amount of zinc oxide (ZnO) and ethane: $H_2O + (C_2H_5)_2Zn \rightarrow ZnO + 2\ C_2H_6$ Zinc oxide remains in the paper and forms the alkaline reserve, protecting the paper against future acidification, as caused by air pollutants and paper oxidation. As there is a direct correlation between the water content of the paper and the amount of zinc oxide formed, the preconditioning step, resulting in a water content of 0.4%, guarantees an alkaline reserve of 1.5–2.0% zinc oxide (1.8–2.5% $CaCO_3$). In connection with the relative insolubility of zinc oxide in water, cold extraction pH values of treated paper do not reach the very high levels found for magnesium carbonate in paper treated with other deacidification processes.

carbon dioxide gas (CO_2) (Kelly 1987). Those developing the system further probably did not attach much importance to the aspect of photo-oxidation, as the after-treatment with CO_2 was dropped later. (Sebera 1990).

In June 1991, the Institute for Paper Science and Technology (Atlanta) reported the results of the tests of the DEZ, FMC and Wei T'o systems, performed by order of the Library of Congress on the basis of the Library's request for proposals (RFP90–32). The test material for each system consisted of approximately 500 books, including a collection of test books that had been assembled to represent a variety of modern papers (LC blue test books). With respect to the DEZ process, several of the findings are worth mentioning. The treated books showed significant changes, such as odor, white residues, rings, cockling, (yellow) discolorations and adhesive bleeding. More than 90% of the books appeared to be completely deacidified by the DEZ treatment, with final cold extraction pH values ranging from 7.55–9.50 (mean value: 7.98) and alkaline reserve contents of 1.0–11.0% $CaCO_3$. It should be emphasized that the high pH and alkaline reserve values found in some of the papers resulted from the fact that these papers were already alkaline prior to treatment. Paper strength measurements and accelerated ageing tests indicated that, with the exception of alkaline-sized paper, the DEZ treatment improves the mechanical stability of the paper (Physical properties 1991a).

At Harvard University the problem of inhomogeneous deacidification of coated paper by DEZ was clearly identified in a test run of 3,700 books. Besides the problem of coated paper, the unpleasant smell after the treatment, and the 'esthetic' damage of approximately 20% of the books, such as discoloration (Newton rings) and white deposit on both paper and covers, were also distinguished as undesirable side effects. Moreover color changes, in particular in 19th-century illustrations, and deleterious effects of the DEZ treatment on bookbinding materials containing cellulose nitrate were recognized as serious disadvantages (Mass deacidification 1993).

The findings of the Harvard University Library were confirmed by the DEZ studies of the mass deacidification survey of the Schweizerische Landesbibliothek (National Library) and Bundesarchiv (Federal Archives), which were performed in cooperation with the Library of Congress and the Wimmis Pulverfabrik. Additional studies by the Swiss, using accelerated ageing tests and measurements of paper strength, clearly indicated a positive effect of DEZ deacidification on the permanence of paper, even though sometimes an immediate loss of paper strength was observed as a direct result of the treatment. However, in their final report it was concluded that neither the DEZ process, nor the other process tested (FMC), met all requirements and that further research was necessary to decide which mass deacidification system would be most suitable for the Swiss libraries and archives (Schlussbericht 1992).

The DEZ process was tested and compared with the FMC and Wei T'o systems by the Canadian Conservation Institute. Studies with sample books, put together from different grades of papers, showed complete and homogeneous deacidification and moderately improved chemical stability for several papers during accelerated ageing. On the other hand the DEZ treatment resulted in a decrease in stability of alkaline- processed wood pulp and cotton offset papers, and also caused relatively much damage to the books, including a very strong odor (Burgess 1992, Kaminska 1994). Additional studies of the Canadian Conservation Institute in order to identify other problems in the treatment of common library and archival collections have indicated that the DEZ process causes serious damage to dry-transfer media, cellulose acetate materials and new parchment (Tse 1994).

Investigations in Belgium, comparing seven mass deacidification systems, concluded that the DEZ system was one of the most promising (Liénardy 1992, 1994). Satisfactory research findings are also reported by the Central Research Laboratory for Objects of Art and Science in Amsterdam (Roelofs 1994) and by the Harry Ransom Humanities Research Center, University of Texas at Austin (Kiesling 1995).

Initial studies of the TNO Center for Paper & Board Research (Delft) dealt with the effects of DEZ on two reference papers and on bound newspaper volumes, and with the process control of the DEZ procedure (Deventer 1993a, Havermans 1993a, 1993b). Subsequently, TNO performed quality checks of four DEZ treatment runs (1993/1994) of archival materials from the Algemeen Rijksarchief (General State Archives of the Netherlands). The quality tests were carried out by the use of reference papers inserted between the original archival materials packed in standard acid-free cardboard archival boxes. The results of the tests indicated in general a homogeneous deacidification and a sufficient alkaline reserve. A case of serious damage, noted in the second run in 1993, stressed the importance of the drying step in the treatment procedure and motivated the introduction of several measures to improve packing of the materials. Although the effects of the DEZ treatment on the mechanical performance of the paper was not discussed in detail in the test reports, the recorded data on paper strength measurements during accelerated ageing do not clearly show an improved mechanical stability (Deventer 1993b, 1994).

Another series of tests on the effects of the DEZ treatment on regular library books has been performed by the Koninklijke Bibliotheek (National Library of the Netherlands). Besides the obvious advantages such as increased pH and increase in useful lifetime, several important disadvantages were reported, such as unpleasant odor of the treated books, local discolorations (Newton rings) on coated paper, uneven deacidification of thick books, and severe damage to synthetic bookbindings (Pauk 1994).

As the expert advisory panel of the Library of Congress had concluded from the studies of the Institute for Paper Science and Technology described above that the DEZ system showed the greatest promise for meeting the Library's technical requirements, the first phase of the Library's Mass Conservation Action Plan was devoted to further refinement of the DEZ process. On the basis of twelve runs in the AKZO pilot plant in Houston it was concluded that the major undesirable side effects of the treatment could be resolved by minor adaptations, i.e. odor and chemical attack on some book covers could be prevented by reducing the temperature during treatment, and rings/white deposits on coated papers could be eliminated by maintaining a sufficiently high DEZ flow rate (Harris 1994).

Application

The extreme reactivity of DEZ makes it necessary for the whole process to take place in a reactor that is strictly protected against leakage. Highly trained personnel is another requirement, and the installation should preferably be located in an industrial area where indispensable facilities such as a fire brigade and a security service are available. Apart from high reactivity there are no other environmental or health risks associated with DEZ.

The requirements for safety, qualified staff and location result in high investment costs for the system (Sebera 1990). Estimates have shown that the DEZ process can only be exploited commercially at a minimal capacity of 250,000 books per year. Such an installation would require a floor-space of 180 m^2 and could treat a total of at least 6 million books, assuming a life of the installation of 25–30 years. At a capacity of 500,000 books per year, the treatment costs per book have been estimated at $ 3.00–3.50, but the actual cost of the treatment per book in the pilot plant was reported to amount to $ 9.00–13.00 in 1988 (Johnson 1988). Later reports mention costs per book, exclusive of transport, of $ 15.00 (Stefansson 1993).

In 1992 the Library of Congress presented its 'Mass Deacidification Action Plan' to the American Congress. This plan included further optimization of the DEZ process and evaluation and testing of other promising deacidification technologies. The results of the first phase of the Action Plan, the refinement of the DEZ process discussed above, were reported in October 1994, 6 months after the closure of the DEZ plant in Houston (Harris 1994).

In order to contribute to the testing of the application of the DEZ process in practice, three other American libraries entered into contracts with AKZO Chemicals, Inc.: the Milton S. Eisenhower

Library of Johns Hopkins University (Baltimore), Harvard University Library, and Columbia University.

In 1991 the Milton S. Eisenhower Library signed a one-year contract ($ 40,000) for the treatment of 4,000 books (Major 1991). The costs per book have been estimated at $ 9.75, exclusive of transport costs (approximately $ 1.00) (Stefansson 1993).

Harvard University Library, which has a long tradition of collection preservation, signed up for DEZ deacidification in 1992 and in the first year spent $ 65,000 for the treatment of 3,700 books and 4,688 maps, at the costs of $ 12.40 per book and $ 4.35 per map, inclusive of transport (Preserving 1991, Harvard 1992, Mass deacidification 1993). Harvard University Library was the first institution which reported test results discussed above of regular DEZ deacidification of books and maps (Mass deacidification 1993).

Columbia University received financial support of approximately $ 11,000 from the 'New York State Program for the Conservation and Preservation of Library Research Materials' for the deacidification and testing of 400 books, in cooperation with the New York University and the State University of New York (Columbia 1993). The withdrawal of AKZO from further exploitation in 1994 led to the disappearance of DEZ from the mass deacidification scene, but serious initiatives are being undertaken by the Rijksarchiefdienst (State Archives of the Netherlands, The Hague) to breathe new life into the DEZ system for preservation of archival materials (De muren 1996, Steemers, pers. comm. 1996).

FMC

Development

The FMC process has been developed by the Lithium Corporation of America (LITHCO) in North Carolina. This firm, being a part of the FMC concern, has specialized in the development and the production of organo-metallo compounds for many different applications. Since 1988 FMC (Bessemer City) is involved in research on mass conservation of paper (Wedinger 1989, Pacey 1992). On the basis of research results FMC has developed a method by which books are treated with carbonated magnesium alkoxide, solubilized in freon-113. Although alkoxides are also used in the Wei T'o deacidification process, described later, the particular alkoxide variant used by FMC, MG-3, is said to result in deacidification as well as strengthening of paper.

In the last few years, several changes have been made in the treatment solution; MG-3 has been replaced by magnesium butyl glycolate (MBG), and the freon by heptane. Because of these fairly extensive modifications, the FMC process has entered into a renewed stage of testing (Wedinger 1993).

Research results

FMC has enlisted an independent research institution to test the effectiveness of their mass deacidification process. The Institute of Paper Science and Technology in Atlanta has investigated the effect of the treatment on different paper properties, using accelerated ageing experiments (Wedinger 1990a,b). The results obtained by the measurements of folding endurance and coppernumber (a measure for paper deterioration) indicated a strong positive effect of the deacidification treatment, i.e. the treated paper showed significantly less degradation compared with untreated reference material. The strengthening effect was evident as well: brittle paper with a fold number of less than 4, yielded increased values up to more than 20 as a result of the treatment. The deacidification of the paper appeared to be homogeneous, resulting in cold extraction pH values of 8.3–9.1, and an alkaline reserve of 0.7–2.9% magnesium carbonate (0.8–3.4% $CaCO_3$).

Although predrying is a necessary step in the treatment procedure, the required final water content (2%) is not as low as with processes using DEZ (0.4%) and Wei T'o (0.5%). This means that more vulnerable books, such as those with leather bindings, need not be excluded from treatment. As the presence of alcohol, like methanol in the case of the alkoxides used by Wei T'o, is not required to solubilize the effective deacidification agent of the FMC process, the risk of damage to inks and adhesives is strongly reduced and consequently preselection is less essential (Wedinger 1989).

As mentioned above, the FMC process was also included in an investigation of the Institute for Paper Science and Technology

Treatment principle

Type of process	FMC/liquid-phase
Effective agent	MG-3, carbonated magnesium dibutoxytriethylene glycolate; MG-3 is described among other alkoxides in the FMC patent of 1989 (Kamienski 1990). In solubilizing the alkoxides in an organic solvent, the carbonated form produces a solution with a relatively low viscosity, resulting in an improved impregnation of the paper, compared to the noncarbonated variants; recently MG-3 has been replaced by magnesium butyl glycolate (MBG).
Solvent	Freon-113; recently replaced by heptane
Procedure	The original treatment procedure, which takes less than 8 hours for completion, consists of three steps: *(i) Predrying:* the water content of the books is decreased to 2.0% by means of a specially developed dielectric drying process. *(ii) Impregnation with MG-3:* the books are placed in the treatment chamber and impregnated for 10 minutes with a solution of MG-3 in an organic solvent (freon). *(iii) Aftertreatment:* the treatment solution is drained and recycled, and the remainder of the solvent in the books is removed by means of dielectric drying; no further reconditioning is recommended.
Initial reactions	In the reaction of MG-3 with the water in paper, butoxyethylene glycol (BTG) and magnesium carbonate ($MgCO_3$) are formed: $MG\text{-}3 + H_2O \rightarrow 2\ BTG + MgCO_3$
Deacidification	MG-3 can directly neutralize the acids in the paper, producing magnesium salt, carbon dioxide and BTG. Both BTG and the excess of MG-3 are adsorbed by the paper and linked to the cellulose chains, resulting in the strengthening of the paper (Wedinger 1989).
Alkaline reserve	The remainder of MG-3 and the produced magnesium carbonate build up the alkaline reserve, protecting the paper against future acidification.

(Atlanta), carried out by order of the Library of Congress. Several findings are worth mentioning. The treated books showed significant changes, such as odor, sticky residues on covers and spine, cockling, and (yellow) discolorations. Over 90% of the books appeared to be incompletely deacidified by the FMC treatment; final cold extraction pH values ranged from 7.05–10.07 (mean value: 7.51) and the alkaline reserve amounted to less than 0.3% $CaCO_3$. Paper strength measurements and accelerated ageing tests indicated that, with the exception of alkaline-sized paper, the FMC treatment reduces the rate of loss of mechanical strength of the paper. Indications for a strengthening effect as a direct result of treatment were not found (Physical properties 1991b).

The modified FMC process, using MBG in heptane, was also part of the Swiss investigations by the Landesbibliothek (National Library) and Bundesarchiv (Federal Archives) in Bern mentioned earlier. The results indicated that the predrying and afterdrying did cause damage after all. This damage seemed to be related to uneven drying which in turn could lead to a non-homogeneous impregnation of the materials with the treatment solution and cause the uneven distribution of the alkaline reserve observed in this study, as well as the prolonged release of the solvent and other volatile (odorous) reaction products after the treatment. Other undesirable side effects, such as local discolorations, were also observed. On the basis of these results it was concluded that the FMC process did not meet the requirements which the Swiss institutions had established for a suitable mass deacidification system (Schlussbericht 1992).

The FMC process was tested and compared with the DEZ and Wei T'o processes by the Canadian Conservation Institute. In this comparative study, which started in 1991, the FMC process was in a stage of development in which the treatment solution consisted of MG-3 in heptane. Studies with sample books, put together from different grades of papers, showed the following effects of the FMC treatment: complete neutralization of acid and good penetration of the deacidification agent in the core of the paper, moderately homogeneous distribution of the alkaline reserve, and improved chemical, and to a lesser extent mechanical, stability during accelerated ageing. On the other hand the FMC treatment appeared to cause damage to all books to some degree, resulted in a markedly increased absorbency of the treated papers which might stimulate the reactivity of the paper to moisture, and caused significant color change, i.e. yellow and translucent staining, of the paper (Burgess 1992, Kaminska 1994). Additional studies of the Canadian Conservation Institute in order to identify problematic materials commonly found in library and archival collections have indicated that treatment with the FMC process causes serious damage to wax seals, pencil crayons, color laser copies, new parchment and polystyrene materials (Tse 1994).

Several disadvantages of the FMC process found in the previously mentioned studies were confirmed in the comparative investigation of A. Liénardy, i.e. paper discolorations and an unpleasant odor of the treated materials (Liénardy 1992, 1994).

Application

Safety and health risks of the FMC process appear to be relatively small, highly qualified personnel is no prerequisite, and the installation can in principle be housed within a library or archive.

On the basis of a laboratory-scale installation reported by R.S. Wedinger (1989), allowing treatment of 20 books at a time, plans for an operational pilot plant with a capacity of 100,000 books per year and a commercial plant with a capacity of 1–3 million books per year have been put forward. Since 1990 the pilot plant operates in North Carolina with an actual capacity of 300,000 books per year. The treatment costs are calculated per weight and have been estimated at $ 14.00–30.00 per kg (Pacey 1992). So far, there are no further developments in the commercialization of the present pilot plant (Wedinger, pers. comm. 1996).

Wei T'o

Development

The Wei T'o firm was founded in 1972 by R.D. Smith and started to develop solutions of magnesium methoxides for the purpose of deacidification. This mass deacidification system resulted from R.D. Smiths' Ph.D. thesis research into a nonaqueous deacidification treatment of paper at the University of Chicago (Smith 1970).

Initially a pressurized solution of magnesium methoxide in methanol and freon-12 (dichloro-difluoro methane, a chloro-fluoro carbon, CFC) was used to impregnate complete books. For deacidification of separate sheets, this solution was supplemented with barium methoxide, freon-11 (trichloro-fluoro methane) and freon-113 (trichloro-trifluoro ethane) and was used as a spray.

An important improvement in the Wei T'o system was the replacement of the effective deacidification agent, magnesium methoxide, by methoxy magnesium methyl carbonate (MMMC). This replacement resulted in the reduction of several undesirable side effects such as a white deposit on the surface of the treated paper and clogging of the spray guns. The improved Wei T'o reagent is used in several libraries and archives, both in large-scale deacidification by hand and in mass deacidification. Since 1982 the Wei T'o mass deacidification system is in operation at the National Archives and National Library of Canada, Ottawa. A temporary cooperation of Wei T'o with Union Carbide was cancelled, presumably due to lack of commercial prospects (Neevel 1991).

As the use of methanol can cause damage to certain inks and adhesives, substantial efforts have been made by Wei T'o Associates, Inc. (Matteson), to minimize the methanol content in the deacidification process and to find an adequate replacement. In addition, an alternative for the freon compounds, which cause deterioration of the ozone layer of the earth, must be found. Although freon-12 can be replaced by the less harmful freon-122, and the Wei T'o mass deacidification is in principle a closed circuit process, environmental restrictions for freons by the governments will ultimately result in serious problems in the exploitation of Wei T'o (Hon 1989, Schwerdt 1989).

Environmental regulations in Canada prohibited the use of freon compounds (chloro-fluoro carbons, CFCs) in the beginning of 1996. To allow the National Archives to meet the new regulations, the National Research Council of Canada undertook a research project in 1993–94, to identify an adequate alternative for the Wei T'o solvent. This resulted in the introduction of a new formula in 1995, in which the original chloro-fluoro carbons (CFCs) are replaced by the more environmentally acceptable hydrochloro-fluoro carbons (HCFCs). However, in January 2000, environmental regulations will become effective in Canada that prohibit the use of HCFCs in any process which does not totally prevent emission of this ozone-depleting substance (Desmarais, pers. comm. 1996).

Research results

Tests with a small series of four books, using treated and untreated copies and accelerated ageing experiments, indicated a general improvement of the permanence of the paper by Wei T'o deacidification (Smith 1987). Groundwood-containing paper showed more benefit as compared to rag paper. More recent studies of Smith on different sorts of paper confirmed the positive effect of the Wei T'o treatment (Neevel 1991).

The deacidified books appeared to be very alkaline, yielding cold extraction pH values of up to 10.3. In addition, the alkaline reserve introduced by the treatment amounted to 1.8–2.5% $CaCO_3$ and had a reasonably homogeneous distribution. The individual sheets of a book showed no more than approximately 10% variation with the mean value for this parameter.

Later reports indicate pH values of 8.5–9.5, and an alkaline reserve between 0.7 and 0.8% $CaCO_3$. Cases of uneven deacidification and white powdery deposits have also been found (Hon 1989, Harvey 1993). The studies of Smith clearly indicated that groundwood containing paper strongly increased in permanence, but later publications mention that these papers generally showed a slight discoloration as a result of the Wei T'o treatment (Harvey 1993).

A serious disadvantage of the Wei T'o system is the presence of methanol in the deacidification solution. Certain binding media applied in writing inks and adhesives dissolve in methanol, which causes irreversible damage. Besides, test results have indicated that some leather bindings can be seriously damaged by the predrying step in the treatment procedure. As a consequence a preselection step is inevitable (Scott 1987); in a report of the Office of Technology Assessment and later studies, the amount of materials that has to be excluded from treatment is estimated at 20–30% of an average library collection (Johnson 1988, Brandt 1992).

The effects of the Wei T'o treatment were investigated in a 500-book test by the Institute for Paper Science and Technology (Atlanta), by order of the Library of Congress. The treated books showed significant changes, such as odor, white residues, rings, cockling, (yellow) discolorations and adhesive bleeding. Approximately 35% of the books appeared to be incompletely deacidified by the Wei T'o treatment; final cold extraction pH values ranged from 7.87–10.43 (mean value: 8.93) and the alkaline reserve amounted to 0.3–4.0% $CaCO_3$. Paper strength measurements and accelerated ageing tests indicated that, with the exception of alkaline-sized paper, the Wei T'o

Treatment principle

Type of process	Wei T'o/liquid-phase
Effective agent	Methoxy magnesium methyl carbonate (MMMC)
Solvent	Mixture of methanol and chloro-fluoro carbons (CFCs); recently the CFCs have been replaced by hydrochloro-fluoro carbons (HCFCs)
Procedure	The Wei T'o mass deacidification process as applied at the Public Archives of Canada consists of four steps (Smith 1987, Scott 1987): *(i) Preselection:* books with certain inks, adhesives and synthetic bookbinding materials are excluded from treatment because of the risk of damage by methanol; the books to be deacidified are placed, spine down, in special baskets, made of steel wire. *(ii) Predrying:* the books are dried for 36 hours using a combination of vacuum and high temperature (60–66°C), in order to decrease the water content from approximately 6% to 0.5%. *(iii) Impregnation:* in a separate treatment chamber the books are impregnated under pressure with the MMMC deacidification solution for 60 minutes, after which the solution is drained and recycled; subsequently the books are dried for 60 minutes under vacuum. *(iv) Reconditioning:* the treatment chamber is brought to atmospheric pressure, and the books are immediately placed in closed boxes for 24–48 hours, in order to prevent condensation of water on the surface of the books and to ensure a very gradual return of a normal water content in the paper.
Initial reactions	Methoxy magnesium methyl carbonate (MMMC) reacts with the water in the paper and forms methanol (CH_3OH) and alkaline magnesium carbonate, a mixture of magnesium carbonate ($MgCO_3$), magnesium hydroxide ($Mg(OH)_2$) and water: $CH_3OMgOCOOCH_3 + H_2O \rightarrow MgCO_3 + 2\ CH_3OH$ $CH_3OMgOCOOCH_3 + 2\ H_2O \rightarrow Mg(OH)_2 + 2\ CH_3OH + CO_2$ $4\ MgCO_3 + Mg(OH)_2 + 4\ H_2O \rightarrow 4MgCO_3.Mg(OH)_2.4H_2O$
Deacidification & Alkaline reserve	The magnesium compounds formed by the initial reactions are able to neutralize the acids in the paper, and build the alkaline reserve.

treatment improves the mechanical stability of the paper (Physical properties 1991c).

In a comparative study, the Wei T'o process was tested by the Canadian Conservation Institute. Studies with sample books, consisting of different grades of papers, showed the following effects of the Wei T'o treatment: complete neutralization of acid and good penetration of the deacidification agent in the core of the paper, moderately homogeneous distribution of the alkaline reserve, and improved chemical, and to a lesser extent mechanical stability during accelerated ageing. On the other hand the Wei T'o treatment appeared to cause some damage to all books and to increase absorbency of the paper, possibly caused by the removal of the initial sizing, which might stimulate the reactivity of the paper to moisture (Burgess 1992, Kaminska 1994). Additional studies to identify problematic materials commonly found in library and archival collections have indicated that the Wei T'o process causes serious damage to wax seals, color laser copies and new parchment bookbindings (Tse 1994).

Several of the disadvantages described in the investigations mentioned above were confirmed in a comparative Belgian study, i.e. bleeding of inks and limited homogeneity in the distribution of the alkaline reserve (Liénardy 1992, 1994).

Application

The Public Archives and National Library of Canada have been applying the Wei T'o mass deacidification technique since 1982. The low safety risks of the Wei T'o system have enabled installation directly on location, resulting in low transportation costs. The built-in plant does not require highly qualified personnel and occupies a floor-space of 120 m^2. Although 260,000 books can be treated per year (5000/week) if the installation is used in continuous operation, the actual number of books treated per year is on average 40,000, at approximately $ 7.00 per book (Johnson 1988). In the 1992 report of A. Pacey an amount of CAN $ 8.33 is mentioned (Pacey 1992).

Although the Wei T'o system was developed initially as a pilot project by the National Archives for the purpose of treating archival as well as library material, it has become clear that the method is not appropriate for archival material. In recent years operation of the system has been entirely for the benefit of the National Library of Canada (Desmarais 1994).

Since the start in 1982, over 890,000 books have been treated. Priority is established by the National Library and is as a rule given to new acquisitions printed on acid paper. Because of the composition of their material some synthetic covers might be affected by the heat used in the predrying, and books with such covers are therefore excluded from treatment. Exclusion of other material is mostly related to ink solubility, especially from photocopies and most laser printers (Couture, pers. comm. 1996).

At the moment the National Archives do not expect to be able to meet the new environmental regulations for the solvent applied in the process, which are expected to come into effect in January 2000; as a consequence it is likely that they will be forced to discontinue the operation of the mass deacidification system (Desmarais, pers. comm. 1996).

Sablé variant

Since 1987, the Bibliothèque Nationale de France (National Library, Paris) has been using a mass deacidification facility in Sablé-sur-Sarthe which operates on the same principles as the Wei T'o system. The Wei T'o deacidification reagents and the treatment procedure have been developed further ever since the beginning of the 1980s (Schwerdt 1989). In pursuing the optimization of the Wei T'o system, the Bibliothèque Nationale de France cooperated with the Centre de Recherche sur la Conservation des Documents Graphiques and the CIM-MALLET firm. Important technical improvements have been made with respect to the recycling of the deacidification solution. The treatment solution consists of a mixture of carbonated magnesium methoxide and ethoxide in alcohol, utilizing freon-134a (tetrafluoro ethane) as co-solvent (Flieder 1989, Brandt 1992, Vallas 1993).

As in the Wei T'o system in Canada, the treatment procedure in Sablé is relatively time consuming, taking 3–4 days including predrying and reconditioning (Dubouloz 1992).

Only few results of investigations into the effectivity of the French Wei T'o variant have been published. In a comparative investigation in Belgium it has been shown that the Sablé process suffers from the same side effects on inks as have been reported in the Canadian system, and that therefore preselection of the material to be treated is a necessity (Liénardy 1992, 1994). It has also been noted that materials with a very high acidity, showing pH values of less than 3.3, cannot be deacidified sufficiently (Brandt 1992, Vallas 1993).

The original plan was for treating 200,000 books per year, but this has not yet been achieved. In the pilot plant 25,000 books (only relatively small-sized volumes) are deacidified per year. The costs per book have been estimated at $ 5.00–15.00 (Stefansson 1993). In 1989 the French Wei T'o system in Sablé was commissioned to start with the treatment of the endangered 19th and 20th century collections of the Bibliothèque Nationale de France. The selected books will be microfilmed, deacidified and, if necessary, restored (Schwerdt 1989, Dubouloz 1992, Vallas 1993).

Further developments in the mass deacidification process of the Bibliothèque Nationale are in progress, both in the Centre de Sablé and in the Centre Technique de Marne-la-Vallée. The process under development uses supercritical carbon dioxide and is aimed at a combined deacidification and strengthening of paper. Pilot investigations by the CEA (Commissariat à l'Energie Atomique) have resulted in a patent, and an exclusive license has been granted to the French company Separex. The development project is partly supported by an innovation loan from ANVAR (Agence Nationale pour la Valorisation de la Recherche). Results of the research program are not yet available in published form, and the internal reports are strictly confidential (Brandt, pers. comm. 1996).

Other initiatives

Bückeburg process

The Bückeburg process in the Niedersächsisches Staatsarchiv (State Archives) in Bückeburg (Germany) has been developed for large-scale deacidification and combined strengthening of archival materials consisting of single sheets of paper. The process involves a sequence of three steps: *(i)* fixation of the inks and dyes, *(ii)* aqueous deacidification by means of a solution of magnesium bicarbonate, and *(iii)* strengthening by methyl cellulose sizing.

The tests performed in the experimental stage of development have indicated that the treatment of paper results in an increase of the pH value to 9.4–10.7, an alkaline reserve equivalent to 2.0% $CaCO_3$, and a reduced loss of mechanical stability during accelerated ageing. Work is still in progress, in cooperation with a commercial firm, to optimize the system.

Since the end of 1995 the process has been operational at the Bückeburg Archive. The capacity amounts to approximately 5 linear meters of archival material (approx. 50,000 sheets) per 30 days. So far only post-1850 materials have been treated, while several types of paper have been excluded, such as paper weighing more than 140 g/m^2, oversized sheets, photographs, zinc oxide copies, and brittle paper (Feindt, pers. comm. 1996).

Graft-copolymerization process

The graft-copolymerization technique is used to strengthen cellulose by means of polymerization of monomers which are introduced in the paper fibers. The possibility of polymerizing mixtures of styrene, methyl methacrylate and ethyl acrylate by means of UV or gamma radiation for the purpose of paper conservation was already reported 25 years ago (Davis 1981). Since then the British Library has instigated research in order to adapt the graft-copolymerization process, which had been tested on separate sheets of paper, to the treatment of complete books, using mixtures of ethyl acrylate and methyl methacrylate and applying gamma radiation (Burstall 1984, 1986). In 1988 the British patent was obtained (Mollett 1988). Though substantial research has been done in the course of time, the treatment process is not yet fully optimized and still remains in an experimental stage. At the moment the British Library is seeking for new funding to continue the further development of the graft-copolymerization process (Mehmet, pers. comm. 1996).

The treatment procedure consists of 7 steps: *(i)* 5–10 books to be treated are placed in a special container; *(ii)* the container is flushed with nitrogen gas in order to remove the oxygen, which can inhibit the polymerization reaction; *(iii)* solubilized acrylate monomers, the amount depending on the weight of the books, are introduced; *(iv)* the books are treated with the monomer solution for several hours to achieve a uniform impregnation; *(v)* the container with the books is exposed for 13–16 hours to a gamma radiation-emitting, radioactive cobalt source, causing the monomers to polymerize and to link to the cellulose molecules; the process is followed by registration of the weight of the books and the temperature, which can go up to 65°C; *(vi)* excess of monomers is removed by evaporation, using air flushing of the container; *(vii)* the books are removed from the container and reconditioned in a well-ventilated storage room.

Satisfactory results were reported with a 5:1 mixture of ethyl acrylate and methyl methacrylate monomers. Addition of small amounts of alkaline monomers could bring about deacidification of the paper, and traces of other monomers increased the effectiveness of the treatment (Mollett 1989).

Several investigations have indicated that paper strength, measured as fold number, increased considerably as a result of the treatment. Groundwood-containing paper and naturally aged paper which had already suffered from deterioration showed the least effect. The standard treatment procedure did not cause bleeding of inks, nor damage to various bookbinding materials. The polymers caused a gain in weight of 15–20% and showed a fairly homogeneous distribution over the individual pages of the treated books. As the radiation dose needed for optimal effectiveness has to be adapted to the dimensions of the books to be treated, relevant statistical data have been collected in advance from the British Library collections for future treatments (Butler 1989).

Apart from the safety risks associated with the use of radioactive sources, which necessitates employment of specially trained staff, no serious health risks have been reported. It has been estimated by the designers of the system that the treatment costs per book would amount to $ 5.00 in an installation with a capacity of 100,000–200,000 books per year (Johnson 1988). Although the development of a commercial installation, exploiting the graft-copolymerization process on a mass scale, has been planned, the operational phase has not yet been reached.

Paper splitting process

For many years, the conservation department of the Deutsche Bücherei (Leipzig) has made substantial efforts to mechanize single steps in restoration procedures and constructed the first mechanized installation for the aqueous treatment of paper (Wächter 1986, Rötzsch 1988).

The paper splitting process has been developed over the past 25 years by W. Wächter at the Deutsche Bücherei in Leipzig, in cooperation with the Friedrich-Schiller Universität in Jena, Germany.

Though basically a system for the treatment of loose sheets of paper, it can also be used for books by separating the sheets of paper first and rebind them after treatment. In principle, sheets of paper are strengthened and deacidified by means of the following procedure: *(i)* on both sides of the paper, sheets of filter paper are pasted, using a mixture of gelatine and glycerine as adhesive; *(ii)* by pulling the two sheets of filter paper apart, the paper to be treated is split in two; *(iii)* after insertion of new, thin polyester-containing paper, both halves of the split paper are pasted together again, the new paper forming a strengthening central layer; the adhesive used in this step consists of carboxy methyl cellulose, to which calcium carbonate, as deacidification agent, and acrylate compounds, as paper strengthening agents, are added; *(iv)* subsequently the gelatine/glycerine layer and attached filter papers are enzymatically removed, and the papers are dried.

By the use of a continuous leafcasting machine, joining the paper sheets to be treated, and moving belt principles, the paper splitting process has been almost entirely mechanized, enabling large-scale application. The Deutsche Bücherei, the Technische Universität Chemnitz, the Landesarchiv Baden-Württemberg in Stuttgart and the firm Fa. Becker Verfahrenstechnik in Korb are working on the construction of the installation located in the building of the Deutsche Bücherei. For the development and construction of the installation, the German Bundesministerium für Forschung und Technologie offered financial support to the amount of DM 1.3 million (Deutsche Bücherei 1993). While the main part of the installation has already been completed, work on the final stage, the removal of the gelatine/glycerine layer and attached filter paper, is still in progress (Wächter, pers. comm. 1996).

Although optimization of the paper splitting installation in the Deutsche Bücherei is still in progress, the results obtained so far in treating newspapers are very promising. At the present level of mechanization and automatization, 2,000–4,000 sheets of paper can be treated daily, at an estimated cost of $ 1.00 per sheet (Bund-Länder-Arbeitsgruppe 1992, Weber 1992).

At present a paper splitting installation is also being constructed in Ludwigsburg, while plans for construction have been put forward by the Garchinger Speicherbibliothek in Germany (Mücke 1989, Mann 1994, Weber, pers. comm. 1996).

Vienna process

This process has been developed in the early 1980s by O. Wächter on behalf of the Austrian Nationalbibliothek (National Library, Vienna). It is intended for the combined strengthening and deacidification of bound newspapers (Wächter 1987b, Cunha 1989).

The treatment procedure consists of the following steps: *(i)* the newspaper volumes are disposed of their bookbindings and divided in 4 cm thick bookblocks, which are placed in a cylindrical vacuum chamber; *(ii)* under vacuum the bookblocks are drained with an aqueous solution of methyl cellulose and polyvinyl acetate as strengthening agents, and calcium hydroxide or magnesium carbonate as deacidification agent; *(iii)* the wet bookblocks are quickly frozen at minus 40°C and subsequently freeze dried; *(iv)* after reconditioning to normal pressure, temperature and humidity, the newspaper blocks are rebound.

The treatment results in an increase of paper strength of up to 4.0 times the original value, measured as folding endurance. There appears to be an evident washing effect due to the aqueous treatment; printing inks show no bleeding damage. Results of accelerated ageing tests have not been reported.

In 1987 the Austrian National Library started a large-scale project, aimed at the treatment of 3,000 newspaper bookblocks per year ($ 15.00 per bookblock), using the Vienna process equipment, which is integrated in the library (Johnson 1988, Liénardy 1994). At the moment approximately 42 newspaper volumes can be treated in 10 days. Especially the freeze-drying step is very time consuming, and the application of supplementary freeze dryers is considered to increase the output. A full description of the treatment procedure and the results of test research will be published shortly (Ruhm, pers. comm. 1996).

Evaluation

The role and merits of mass deacidification in preservation of library and archival materials have received a great deal of attention in the last decade. Several crucial issues have induced heated discussions; various, sometimes contradicting views, have been put forward in the specialist literature and elsewhere and caused considerable confusion. The primary points of controversy relate to:

i. the necessity of preselection of materials to be treated;
ii. the actual contribution of deacidification to the permanence of paper;
iii. the reluctance of institutions to make use of available mass deacidification methods, and
iv. the place of mass deacidification within the whole field of (mass) preservation activities.

In the following, these four aspects, presented in the form of questions, are discussed on the basis of the relevant data on the main mass deacidification systems collected in this report. In addition, opinions of a number of experts, who have been asked for their comments on the basis of a questionnaire, have been incorporated.

1: Which materials will actually benefit from mass deacidification, and which materials have to be excluded from treatment?

There appears to be a general consensus on the type of paper that benefits most from deacidification: paper which is acidic, such as alum-rosin-sized and groundwood-containing paper, paper produced under acidic conditions, and paper of all types which has become acidic through pollution. If such papers are still strong enough to be used, then mass deacidification can be expected to prolong their useful life. However, if they are already brittle or very weak, deacidification alone cannot be expected to recover their usefulness.

The idea that brittle paper should not be mass deacidified is contradicted by some research indicating that deacidification of such materials can significantly slow down their rate of degradation. It would be preferable to reformat all brittle paper as soon as possible, but the reality is that funding limitations and logistics simply do not allow this. From this perspective, by reducing further degradation mass deacidification could 'buy precious time' for the preservation of brittle materials.

Both the research results and the application data of the main mass deacidification processes show that a preselection step appears to be unavoidable for all systems. Preselection criteria depend upon the strength and weaknesses (limitations) of the respective deacidification process. The serious problems specific materials present when treated by a particular process argue strongly for their exclusion from treatment by careful preselection. In general, the materials that have received most attention in this respect include coated paper, (writing) inks, dyestuffs, oversized (thick) books, leather, parchment and synthetic bindings. Although efforts to refine the techniques used in the individual processes have of course focused on these specific problems and improvements in the treatment process have often been realized in the course of time, this is not the place to judge the significance of these improvements and the benefits they may provide.

A type of paper to which insufficient attention has been given so far is pigment-coated paper for printing, which is found in many books and increasingly so today; not much is known about the special problems these papers might pose in mass deacidification processes.

Modern papers in general will hopefully not create similar problems in the future if they are made to one of the new standards for 'permanence'. It should be mentioned in this connection that there seems little point in indiscriminately treating any new acquisition, even when it has obviously been printed on non-acidic paper. It has been said that we will have to select out and avoid treating materials printed on alkaline and permanent papers, and the preceding sections dealing with applications of the various processes show that this is indeed sometimes done. The argument 'if it does not do any good, it does not do any harm either' may in fact not apply to the deacidification of weakly acidic and non-acidic paper. This problem may lie with the high alkalinity that can be reached by treatment, especially with liquid-phase deacidification systems. There are serious concerns about the long-term effects of the resulting high pH values on the chemical and mechanical stability of these papers, and this issue deserves further investigation.

2: What is the real quantitative contribution of deacidification to the permanence of paper?

With all mass deacidification processes discussed in this study, treatment has a positive effect on the permanence of paper in the long term, which means that with the use of accelerated ageing tests in combination with paper strength measurements it has been shown that degradation of treated paper is slowed down, compared with untreated reference papers.

On the other hand, the research results reviewed in the preceding chapters have also indicated that despite this *long-term* positive effect, often a loss of paper strength is caused as a *direct,* immediate result of deacidification, an effect that varies in magnitude with the different mass deacidification systems. Questions with regard to the practical consequences of this reduction in mechanical stability and the amount of time it will take to reach the turning point when the treated paper will have a better performance than the untreated, cannot yet be answered.

The *quantitative* assessment of the increase in useful lifetime that can actually be achieved by the treatment is also a complex issue and is primarily connected with the reliability of artificial ageing tests. Although the real prognostic value of these tests is often seriously doubted, for instance because standard accelerated ageing experiments do not take into account several factors that will have an influence in practice, such as air pollutants and use, it must be emphasized that these tests are at the moment the best measure available of how papers deteriorate under certain conditions.

The extant differences in requirements and specifications established for (mass) deacidification processes lead to confusion and to misinterpretation of research results. Therefore, for the sake of a reliable and useful evaluation of the impact of deacidification on paper permanence, there is an urgent need for standardization of both evaluation criteria and test methods, and for further research into the 'translation' of artificial ageing into practice.

3: Is it justified to wait for an 'ideal' mass deacidification method or can/must we start now?

None of the existing methods conforms to the requirements of a genuinely 'ideal' mass deacidification process, as it has been shown convincingly that each system has both its strengths and weaknesses. Besides the safety and environmental risks connected with some of the deacidification agents and/or the solvents used, the limitations, more or less severe for the different systems and the different materials treated, vary from non-homogeneous deacidification to side effects hazardous to the paper and/or bookbinding material, including discolorations, color changes, staining, Newton rings, odor, bleeding of inks, dyestuffs and adhesives, and morphological changes (bubbling, cockling, change of 'feel'). Optimization efforts focus on these limitations, and test studies have often been carried out over a period of years on plant units which have gradually evolved from the prototype to the pilot stage. As research reports on the efficiency and effectiveness of the mass deacidification processes do not always accurately indicate the precise stage of development of the system under study, research results cannot be always interpreted reliably.

If there is some reluctancy with libraries and archival institutions to apply mass deacidification, this cannot be explained only by the fact that there is no 'ideal' method or by lack of money. Perhaps an additional problem is introducing into a library community what is essentially a chemical engineering process. However, a 'wait and see' policy cannot be recommended as it has been shown that this will inevitably cause companies to withdraw and give up work on systems for the commercial market, which eventually might result in the undesirable situation that further development of promising techniques will no longer be possible at all.

Many of the current objections to mass deacidification techniques in fact lose their validity once it is generally agreed that any 'mass' process should be applied only to non-unique objects of low intrinsic value. If the preselection process screens out the intrinsicly valuable materials, which should be treated individually, the problems reported for mass deacidification systems can be considered minor compared to the benefits. The time lost in worrying about these minor problems may represent a substantial portion of the lifetime of many of the materials to which the treatment could be applied.

Taking into account the specific nature of their collections and the financial and organizational conditions, institutions should be able to decide on the basis of existing knowledge about possibilities and limitations of the currently available mass deacidification techniques which of the systems optimally fits their needs and to what extent they could make use of its service. It should be stressed that regular and independently performed tests and quality control of the treated materials will remain an essential requisite. A useful and exhaustive overview of the various evaluation factors which should be taken into account in choosing mass deacidification processes has been published by the CPA (Sparks 1990).

4: What is the place of mass deacidification in the whole field of (mass) preservation activities?

The current application of mass deacidification techniques in practice shows clearly that mass deacidification is no longer considered as a panacea. In general, institutions using mass deacidification treatment also take other mass preservation measures, such as creating optimal storage conditions and microfilming.

Mass deacidification can be considered to a large extent as a 'preventive preservation' measure, which should become integrated into an institution's preservation culture and should be viewed primarily as a complementary preservation option in a balanced institutional preservation program. However, within the framework of preservation of library and archival materials, mass deacidification will have an essential place, as it is evident that, given the costs and time involved, single-sheet deacidification cannot cope with the enormous amount of acid paper from the 19th and 20th century. Mass deacidification is a relatively inexpensive method to preserve the large amount of 'normal' books published in the time of acidic paper production.

Besides environmental control, mass deacidification can be qualified as a true 'mass' process and it stands alone as the one mass process that can be used on a huge number of objects which can be confidently assumed to have a specific problem in common: acid.

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List of contacts

Bakowska, A., Archiwum Glówne Akt Dawnych, Warsaw, Poland

Bansa, H., Bayerische Staatsbibliothek, Bavarian State Library, München, Germany

Baron, G., Staatsbibliothek zu Berlin, Berlin, Germany

Bartholdy, N.G., Statens Arkiver, Riksarkivet, Copenhagen, Denmark

Behrens, U., Department Papersave, Battelle Ingenieurtechnik GmbH, Eschborn, Germany

Bell, O., Libertec Bibliothekendienst GmbH, Nürnberg, Germany

Berninger, E.H., Deutsches Museum, München, Germany

Bierwagen, M., Bibliothek für Bildungsgeschichtl. Forschung, Berlin, Germany

Björdal, L., Uppsala University Library, Uppsala, Sweden

Brandt, A.-C., Bibliothèque Nationale de France, Paris, France

Burd, J.E., Preservation Technologies, Inc., Cranberry Twp, PA, USA

Calvini, P., Soprintendenza ai Monumenti, Genoa, Italy

Coates, P.R., South African Library, Cape Town, South Africa

Couture, R., National Archives of Canada, Ottawa, Ontario, Canada

Crocco, S., Pittsburgh Theological Seminary, Pittsburgh, PA, USA

Desmarais, E., National Archives of Canada, Ottawa, Ontario, Canada

Deter, I., Max-Planck-Institut für Europäische Rechtsgeschichte, Frankfurt, Germany

Dettmer, K., Landesarchiv, Berlin, Germany

De Vos, W., Koninklijke Bibliotheek Albert 1, Brussel, Belgium

Dorsten, J.v., Archimascon B.V., Rotterdam, The Netherlands

Durovic, M., Státní Ustredni Archiv, Central State Archives, Prague, Czech Republic

Erdmann, J., Landesbibliothek, Coburg, Germany

Erhardt, D.W., Conservation Analytical Laboratory, Smithonian Institution, Washington, DC, USA

Erlande-Brandenburg, A., Archives de France, Paris, France

Faber, W., Archiwum Glówne Akt Dawnych, Warsaw, Poland

Feindt, W., Niedersächsisches Staatsarchiv, Bückeburg, Germany

Foot, M.M., British Library, London, United Kingdom

Frieder, R., Northwestern University Library, Evanston, IL, USA

Fröjd, I., Uppsala University Library, Uppsala, Sweden

Ganser, J., Bundesarchiv, Koblenz, Germany

Gaydos, R.M., Preservation Technologies, Inc., Cranberry Twp, PA, USA

Gonçalves, J.S., Instituto da Biblioteca National, Lisbon, Portugal

Graf von Duerckheim, M.E., J.S. Gericke Library, University of Stellenbosch, Stellenbosch, South Africa

Gubkin, S., Case Western Reserve University Library, Cleveland, OH, USA

Harris, K.E., Library of Congress, Washington, DC, USA

Havermans, J.B.G.A., TNO Center for Paper & Board Reserch, Delft, The Netherlands

Herion, S., Schweizerische Landesbibliothek, Swiss National Library, Bern, Switzerland

Hernández, F., Bibliotheca Nacional, Madrid, Spain

Hoel, I.A.L., Royal School of Librarianship, Copenhagen, Denmark

Hofenk de Graaff, J.H., Central Research Laboratory for Objects of Art and Science, Amsterdam, The Netherlands

Hofmann, R., Bundesarchiv, Koblenz, Germany

Jordan, S., Hesburgh Library, University of Notre Dame, Notre Dame, IN, USA

Kastaly, B., National Széchényi Library, Budapest, Hungary

Kellerhals, A., Schweizerisches Bundesarchiv, Swiss Federal Archives, Bern, Switzerland

Kellerman, S., Pattee Library, Pennsylvania State University, University Park, PA, USA

Leichert, G., Universitätsbibliothek Mannheim, Mannheim, Germany

Liers, J., Deutsche Bibliothek, Deutsche Bücherei, Leipzig, Germany

McIntyre, J.E., National Library of Scotland, Edinburgh, United Kingdom

Mehmet, S., British Library, Londen, United Kingdom

Nebiker, R., Schweizerisches Bundesarchiv, Swiss Federal Archives, Bern, Switzerland

Olszewski, A., Cleveland Public Library, Cleveland, OH, USA

Palm, J., Kongelige Bibliotek, Royal Library, Copenhagen, Denmark

Paulusová, H., Státní Ustredni Archiv, Central State Archives, Prague, Czech Republic

Peltikoglou, V., National Library of Greece, Athens, Greece

Priest, D.J., Knutsford, Cheshire, United Kingdom, retired from:, U.M.I.S.T., Manchester, United Kingdom

Ruhm, W., Österreichische Nationalbibliothek, Austrian National Library, Vienna, Austria

Schoonmaker, D., Oberlin College Library, Oberlin, OH, USA

Sebera, D., Preservation Consultant, 209 Tenth Street SA, Washington, DC USA

Shahani, C.J., Library of Congress, Washington, DC, USA

Staub, K.H., Hessisches Landes- und Hochschulbibliothek, Darmstadt, Germany

Steemers, T.A.G., Rijksarchiefdienst, State Archives of the Netherlands, The Hague, The Netherlands

Trapp, C.-M., Bayerische Staatsbibliothek, Bavarian State Library, München, Germany

Wächter, W., Deutsche Bücherei, Deutsche Bibliothek, Leipzig, Germany

Walter, K.L., Love Library, University of Nebraska-Lincoln, Lincoln, NE, USA

Weber, H., Landesarchiv Baden-Württemberg, Stuttgart, Germany

Wedinger, R.S., FMC Corporation, Bessemer City, NC, USA

Welle, W.-D., Bundesarbeitsgericht, Kassel, Germany

Wenzel, H.-H., Department Papersave, Battelle Ingenieurtechnik GmbH, Eschborn, Germany

Wolf, J.R., Hessisches Staatsarchiv, Darmstadt, Germany

Zappalà, A., Università di Udine, Udine, Italy

Zappalà, M.P., Instituto Centrale per la Patologia del Libro, Rome, Italy