Part II

Comparison of Alternatives for Book Preservation and Deacidification

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INTRODUCTION

Part II of this report discusses possible alternatives to the Library's proposed deacidification system. The main alternatives that are described are the Wei T'o, Bookkeeper (Koppers), and Interleaf Vapor Phase Deacidification processes. Advantages and disadvantages of these three main alternatives to the Library's DEZ process and an ideal deacidification system are discussed along with the effectiveness; costs; and impacts on safety, health, and the environment.[1] Other processes that OTA obtained information on, but was unable to thoroughly analyze are identified in this section of the report. The potential for increasing the use of acid-free paper and what effect, if any, this might have on the Library's program, is also discussed.

[1] Separate cent ractor's report to 01'.4 comparing the effectiveness of these processes is also available from OTA upon request: David N.S. Hon. "An Evaluation of Mass Deacidification Processes for Book Preservation and a Comparison of Their Chemical Characteristics and Effectiveness, Clemson, SC, November 1987.

ALTERNATIVE PROCESSES

Wei T'o

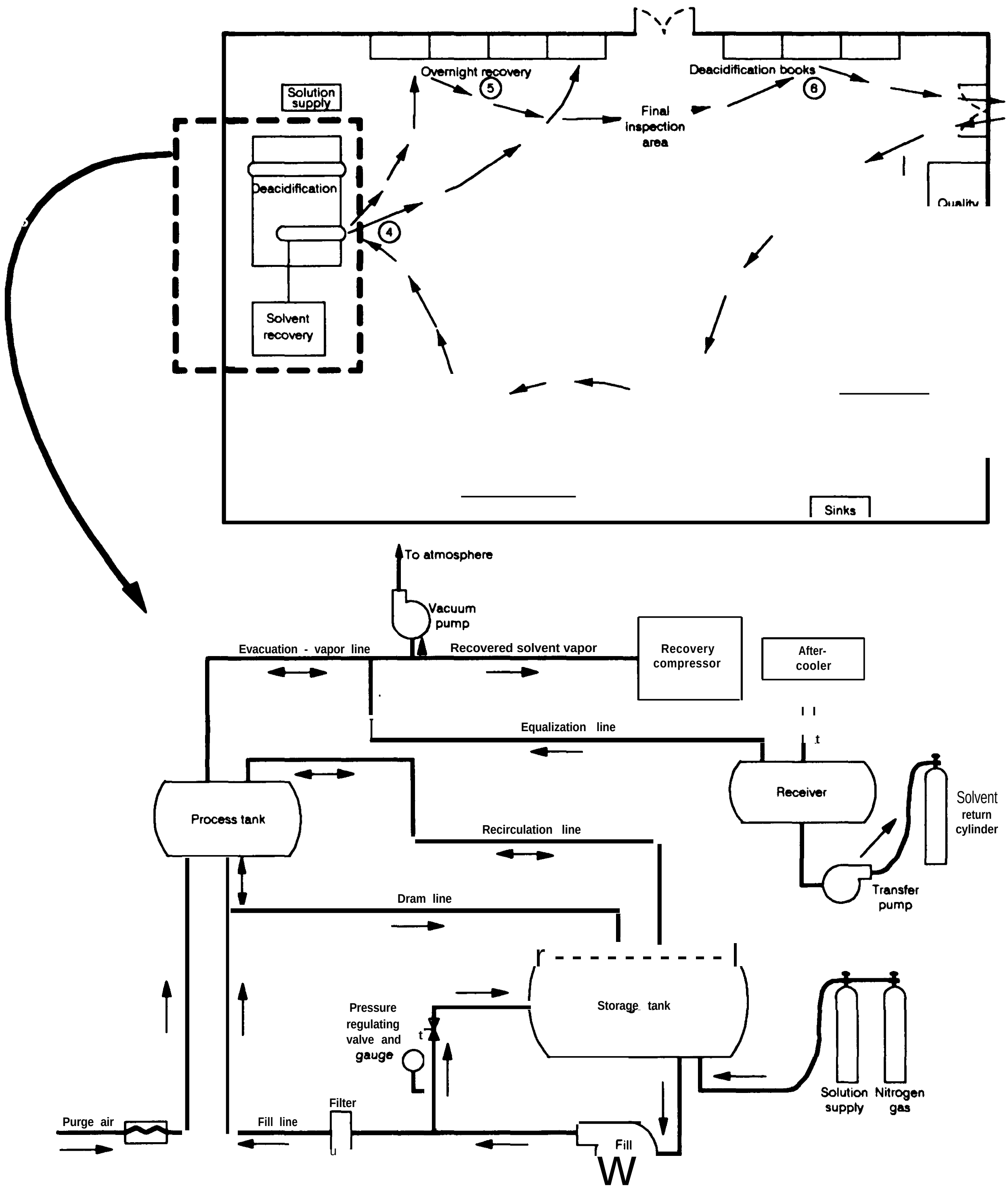
The mass deacidificiation process developed by Wei T'o Associates is a nonaqueous liquid process that uses the same basic chemistry as the manual Wei T'o processes currently in use in many libraries. A mass deacidification pilot plant was built for the Canadian National Library and National Archives in 1979. The plant was designed to treat 30 books at a time. Since 1981, the Canadian Library and Archives have been operating the system on a semi-production scale basis, treating about 120 to 150 books per 8-hour day. The Canadian Library has no immediate plans to scale-up the process. Wei T'o has a preliminary design and cost assessment for a system that would double the batch size and optimize the system's throughput.

The Wei T'o process uses methoxy magnesium methyl carbonate dissolved in methanol, and mixed with Freon 12 and Freon 113. These freons are liquid gases, normally used as refrigerants, that allow the methoxy magnesium methyl carbonate/ methanol solution to penetrate into the paper. Books are immersed in the solution and the methoxy magnesium methyl carbonate reacts with moisture in the books, theoretically forming magnesium carbonate, magnesium hydroxide, and magnesium oxide. These compounds will react with acids in the paper to form stable, neutral salts. Excess magnesium carbonate, hydroxide, and oxide will join together to form a mixture (called basic magnesium carbonate) that acts as the alkaline buffer.

The system in place at the Canadian Library includes a warm air drier, a vacuum drier, and the processing unit, which includes the processing chamber, a storage tank, and a recovery tank and condenser (see figure 22). The storage tank holds the Wei T'o solution under pressure. To begin treatment, the solution is pumped through a filter to remove impurities such as paper fragments loosened from books into the processing chamber. After treatment, the solution flows back into the storage tank for reuse. Vapors from the chamber are evacuated and passed through a condenser and fed into the receiving tank, which can then be sent back to Wei T'o for reprocessing.

Selected books are placed in metal crates and dried in warm air to remove a large amount of moisture. Before being treated, the books are placed in first one and then a second vacuum drier to reduce the books' moisture content to 0.5 percent. In the second vacuum drier the books are heated

Figure 22. - Wei T'o Process [Steps in Sequence O]



SOURCE: R D Smith, "Mass Deactdification at the Public Archives of Canada;" Co*nservation of Library and Archival Materials* and Graphic Arts; Guy Petherbrige (ad) (London: Butterworth's, 1967) to about 1000 C and held there overnight at a pressure of 0.2 torr. The books must be dry to allow good process control. Total drying time is about 24 hours.

The books are then transferred to the processing chamber. The chamber is bolted closed and a vacuum pump evacuates the air and moisture from the chamber. The books must be treated in a dry environment because the solution will react with excess moisture and turn into a gel. When the chamber has been evacuated, it is backfilled with vapors recycled from the receiving tank, equilibrating the process chamber pressure with the storage tank pressure. This is done to avoid any turbulent flow when the solution is fed from the storage tank into the process chamber. The solution is introduced slowly to avoid forming any bubbles that may result in non-uniform impregnation of the books. Once the chamber is filled, it is stabilized for 4 minutes and then more solution is added to increase the pressure in the chamber. The chamber is left under pressure for roughly 40 minutes to allow adequate penetration of the solution into the books' pages.

When the treatment is completed, the solution is drained back into the storage tank, After the chamber has been completely drained, a vacuum pump removes all the excess vapors, routes them through a condenser, and the liquid is stored in the receiving tank. This removes a large fraction of the excess solution and freon left in the books. The chamber is then purged with warm air and opened. The crates are removed and placed in a storage cabinet overnight, where the remaining solution and freon evaporates until the books warm up and regain a portion of their original moisture content. They regain the rest of their moisture slowly after leaving treatment.

The chemical treatment step takes about 1 hour. This includes the time it takes to pull another vacuum on the chamber after the books have been removed to minimize the amount of vapors left in the chamber and eliminate fouling of the chamber. Total cycle time is roughly 26 hours plus the cabinet storage time after treatment. The Canadian plant treats about four to five batches of 30 books each per 8-hour day with two operators for the entire plant or about 42,000 books per year.

Bookkeeper Process

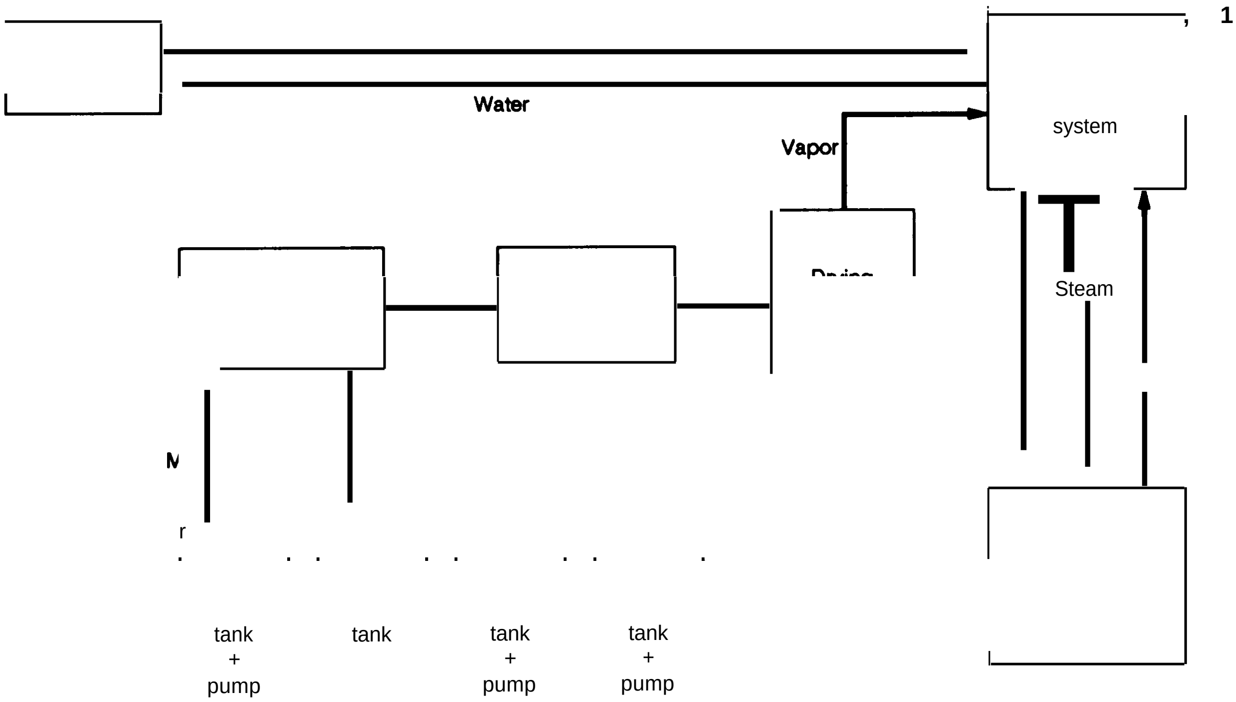
The ' 'Bookkeeper" process is a nonaqueous liquid process that was initially developed by the Koppers Chemical Co. beginning in 1981. Development progressed to a detailed design of a pilot facility capable of treating 100 books per day. An agreement was negotiated between Koppers and The University of California at Berkeley to construct and demonstrate the pilot system at the university. Koppers halted the project, however, after they concluded that the Library of Congress was committed to the DEZ process and that the private library business potential was too limited. Koppers has since sold the patent to Richard Spatz, who recently retired from Koppers. In 1987 Mr. Spatz contracted with Koppers to have the original development team continue work to improve the system under the name ' 'Bookkeeper.

The "Bookkeeper" process uses a suspension of fine (submicron) particles of magnesium oxide dispersed in a fluorocarbon (e.g., Freon 113) and a surfactant. No solvents such as methanol are used, The fluorocarbon carries the particles into the paper and the surfactants keep the particles evenly dispersed in the mixture. The process does not immediately neutralize the acids present in the paper. Rather, when the books are immersed in the mixture, the magnesium oxide particles are implanted into the paper and deacidification occurs later as the acids migrate to and react with the particles over time.

The process is capable of being designed as either a batch or a continuous process. The pilot plant was designed as a batch process and designed to fit in a tractor trailer. It consisted of storage/mixing tanks, a loading area, a treatment tank, and a drier/condenser. (See figure 23,)

Books do not have to be predried in this process. Books (current designs hold three books) are loaded into a fixture that spreads the books open to a specified angle. The fixture is then lowered into the treatment tank and the tank is filled with the mixture. The fixture is then mechanically agitated while the mixture is circulated to ensure complete wetting of the book and its pages. The fixture is designed to close the books before they are removed from the tank. Treatment takes only a few min-

Figure 23.-Bookkeeper Process



SOURCE: Adapted from a Koppers Diagram

utes. The books are then removed from the fixture and placed in an air drier. The vapors from the drier are condensed and recycled. Total process time is 4 to 5 hours.

Experiments are currently being performed that place a book fixture, holding about 10 books, in a processing chamber similar to the kind used in the Wei T'o process. The chamber is then filled with the mixture and the books agitated. After the chamber is drained, it is evacuated by a vacuum pump for about 1 hour to evaporate the majority (about 95 percent) of the mixture remaining in the books. Warm freon vapors are then passed through coils in the chamber and the remaining 5 percent of the mixture remaining in the books after treatment is evaporated under vacuum. In this new development, total cycle time may be about 3 hours.

Interleaf Vapor Phase Deacidification (VPD)

The Interleaf process is a vapor phase deacidification process developed in England by Langwell in the 1960s. The patents to the product have been purchased by B.G. Robertson Laboratories. Interleaf, Inc. of Minneapolis is the sole U.S. distributor.

The VPD process uses cyclohexylamine carbonate crystals that are either impregnated on a sheet of paper or placed in a packet that is then placed between the pages of the books to be deacidified. Cyclohexylamine carbonate is a organic derivative of ammonia and is volatile at room temperature. The crystals release vapors that neutralize acids as they permeate through the pages of the book. Placing the packets takes only a few minutes and complete book deacidification is achieved slowly over several days.

The technique is being used at the Public Records Office in London and the United Nations in Geneva. In this country, Interleaf offers this service to customers that are having books rebound and sells the packets to the general public. The largest deacidification project that Interleaf has done involves the deacidification of 1,200 to 1,500 books from a small law book collection. Books are treated in batches of 100 and placed in boxes for 10 to 12 days and then removed.

ADVANTAGES AND DISADVANTAGES OF THE ALTERNATIVE PROCESSES

It is not possible to make a definitive comparison of the various processes at this time. Data assessing the effectiveness of the processes are limited and those that do exist do not fully assess the processes' effect on paper. Nor have any of the processes been developed enough to allow for an accurate assessment of the potential treatment capacities or costs. However, for DEZ and three major alternatives, OTA has made qualitative comparisons of process effectiveness; capacities and costs; and safety, health, and environmental impacts. The results of these comparisons, against an ideal system, are shown in table 16.

Effectiveness

There is a general lack of meaningful data to compare the effectiveness of the various processes. The effects the various treatments have on the chemical properties and behavior of the various chemical components of paper— including cellulose and its hydroxyl and carbonyl functional groups, hemicellulose, and lignin—have not been given much attention. Data on the effect of treatment on optical properties of paper are also limited. Nor has the stability of treated papers to light, pollution, and other degradation mechanisms been properly evaluated. The effects various treatments have on mechanical properties have received the most attention, but the results that have been reported are not conclusive. The change in the degree of polymerization, which some paper chemists feel is a more definitive measure of a process' effectiveness, has not been measured.

The data that do exist have been generated over a long period of time by the individual developers, on different types of papers, under a variety of test conditions, measuring only a few of the important properties. Ideally, a definitive assessment would require a direct comparison of paper specimens treated by the various processes and tested under identical conditions.

Nevertheless, OTA has made a qualitative comparison of the effectiveness of the various processes (shown in table 16) based on the following criteria:

- the need for preelection (i. e., screening) and predrying before treatment;
- cycle times;
- complexity of the treatment plant;

Table 16.—Comparison of Alternative Mass Deacidification Processes, As of January 1988

Criteria	Ideal	DEZ[a]	Wei T'o	Bookkeeper[b]	VPD[c]
Preelection of books	No	No	Yes	Minimal[d]	Yes
Predrying	None	Yes	Yes	None	None
Impregnation time	Short	Long	Short	Short	Very long
Treatment plant	Simple	Complex	Less complex	Simple	Very simple
Effect on inks and colors	None	None	Some	Minimal[d]	Some
Effect on plastic covers	No	No	Yes	Minimal[d]	Yes
Neutralization	Complete	Complete	Needs verification	Needs verification	Partial
pH of treated paper	7.0-8.5	7.0-7.5	8.5-9.5[e]	8.0-9.0[e] (surface)	5.0-8.7
Alkaline reserve	About 2%	1.5-2,0°/0	0.7-0 .8%[e]	2 %[e]	None
Danger to health	None	Risk of fire	Uncertain[f]	Uncertain[f]	Uncertain
Impact on environment	None	Low	Uncertain[g]	Uncertain[g]	Low
Stage of development	—	Operating pilot plant (2 me.)	Operating pilot plant (7 years)	Lab tested pilot design	Commercial
cost	–	Moderate to high[h]	Low to moderate[h]	Low[h]	Low[h]

[a]Library of Congress' DEZ Process.
[b]"Bookkeeper" submicron particle process.
[c]Langwell vapor phase deacidification process—distributed by Interleaf, Inc.
[d]Based on telephone conversation with Dr. J.J. Kozak of Koppers (Nov. 2, 1987). No independent assessment.
[e]No formal independent analyses have been made, Manufacturers data indicates complete neutralization under laboratory conditions.
[f]Initial indications are good but no formal assessments have been made.
[g]Some concern about the future regulation of fluorocarbons used in these processes.
[h]Based on OTA analysis and extrapolation of limited cost data furnished by developer of each system.

SOURCE: David Hen, "An Evaluation of Mass Deacidification Processes for Book Preservation and a Comparison of Their Chemical Characteristics and Effectiveness," prepared for OTA, November 1987.

- effect on inks and colors, plastic book covers and other materials;
- completeness of neutralization and pH after treatment;
- amount of alkaline reserve after treatment;
- impacts on health and environment;
- stage of development; and
- cost .

In small-scale tests the DEZ process can, very impressively, neutralize all excess acids in the paper and deposit a uniform alkaline buffer. Deacidification byproducts are neutral and stable. An advantage of the DEZ process over all the others is that the initial deacidification occurs independently of the alkaline buffer deposition. As a result, all papers are left nearly neutral after treatment, no matter what their original acid contents may have been. Furthermore, the amount of alkaline buffer deposited can be controlled to a much greater extent and achieve a greater uniformity within a book. However, the uniformity and completeness of treatment from book to book depends on the flow characteristics of the gases in the chamber and the characteristics of papers in the books. Whether very uniform results can be achieved routinely in a full-scale operation must still be demonstrated.

Based on process tests to date, preelection for the DEZ treatment will probably not be needed. The DEZ treatment appears to be compatible with most other book materials including inks, colors, and pigments. It may cause some loss of brightness in nitrocellulose covers. The problem of excess zinc oxide deposits on book covers can be minimized, but depends on the flow of gases in the chamber. The DEZ treatment may leave a slight odor immediately after treatment.

The zinc oxide buffer could increase paper's sensitivity to photodegradation. This is of concern to the Library and they are planning further tests. Some other long-term effects must also be studied further: such as the effect of DEZ/nitro-cellulose reactions. The Library claims that the DEZ process can extend the life of a book three to five times based on fold endurance of test papers. The data that have been presented to support this have not been presented conclusively for the actual books in the Library's collection. Such an evaluation is planned as part of the quality control program that will be developed and tested at the Texas Alkyls pilot plant.

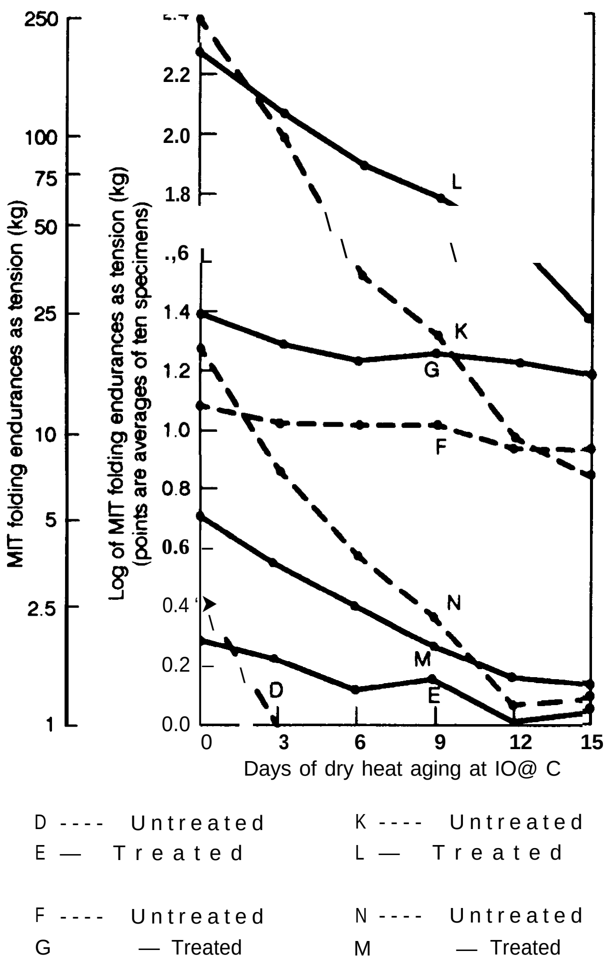
The Wei T'o plant is simpler than the DEZ plant and its chemistry is generally accepted within the preservation community. There is little data, however, on the uniformity of treatment in a mass deacidification system. An examination of one of the books treated when OTA visited the Canadian facility indicated that there were spotty areas where the pages had not been deacidified. Whether this was an isolated case that could be remedied by adjusting the solution concentration or adjusting the process parameters is not known. The alkaline buffer deposited is comparatively small relative to the other processes. The plant also does not appear to have been subjected to a systematic quality control program and no process test results are available.

The Wei T'o process requires pre-inspection of all books about to be treated. The solvents used in the process are known to cause certain colors to transfer and certain inks to run. Experienced operators can determine which books may be affected by simple inspection. With inexperienced operators or when encountering unfamiliar papers and colors, the particular pages must be tested to determine what effect the process may have. Some books cannot be treated at all, others can be treated after placing blank paper between the color pages. Because of its relatively high alkalinity, the Wei T'o process can also cause discoloration after treatment if the paper is exposed to high humidity or water. Certain plastic covers will crack and flake. The reason for this is not known. It may be related to the difference in thermal expansion between the plastic coating and the paper cover. The books cool quickly as the freon and methanol evaporate from the books after treatment. The process does not leave any odor in the books. These various constraints cause rejection of about 20 to 25 percent of the books submitted for treatment.

According to its President, Wei T'o is developing new chemicals for its processes. He claims that new non-alcoholic solvents are being developed to eliminate the problems of color transfer and ink swelling, and that magnesium will be replaced in the deacidifying agent to lower the alkalinity of the treated paper and reduce the problems of discoloration. The status of these new developments is not known.

The long-term effect of the Wei T'o process on various paper properties has not been adequately studied. There is limited published evidence that the mass deacidification system now in use extends the life of books. Some fold endurance test results are shown in figure 24. While improvements in the papers are evident, the description of test conditions and test data is not sufficient for an evaluation of the significance of results.

Figure 24. -Fold Endurance After Aging of Papers Treated by the Wei T'o Process



SOURCE: R D Smith, *Conservation of Library and Archival Materials* and *Graphic Arts*; "Mass Deacidification at the Public Archives of Canada," Guy Petherbndge (ad) (London: Butterworth's, 1987)

The Bookkeeper process can achieve a uniform deposition of magnesium oxide throughout the pages of a book. Tests of this have been based on x-ray diffraction analysis and scanning electron microscopy. The treatment can also effectively neutralize acids, raising the pH of papers up to 8 or 9. Tests by the developer have shown that fanning the pages of bound volumes is necessary to assure complete treatment and uniform pH values from outer edges to the binding. However, only surface analyses have been performed. Cold extraction pH measurements have not been made. Since total deacidification depends on the original amount of magnesium oxide that gets deposited, it is important to know how much buffer is left to inhibit reacidification. The Bookkeeper developer has done an initial microscopic study of treated paper which shows evidence of some penetration of magnesium oxide particles, but a more extensive test program is needed.[2] If the process proved not to completely deacidify the interior of papers, it would be a serious drawback to its use.

The Bookkeeper process is the simplest of the mass deacidification systems and may require the shortest cycle time.

The Bookkeeper process may require little preelection, but the effects of the treatment on paper and other book materials has not yet been adequately studied. Because of the chemicals used in the Bookkeeper process, certain problems associated with color transfer and ink swelling should not be expected. The problem with certain plastic-covered books may present a similar problem for the Bookkeeper process as it does to the Wei T'o process, since it too uses freon that will quickly evaporate after treatment. The process does not leave an odor in the treated books.

As with the other processes the long-term effects of the treatment on the life and other properties of paper have not been adequately studied. Some fold endurance tests have been conducted, and the results are comparable to those for both the DEZ and Wei T'o processes. (See table 17.) Based on this limited data, Bookkeeper claims that the life of a book can be extended two to three times.[3]

'Letter from Richard E. Spatz with enclosures, Dec. 29, 1987.
'Kundrot Patent, U.S. Patent No, 4,522,843, Jan, 11, 1985, p. 5.

Table 17.–Accelerated Aging Effects on Fold Endurance of Treated and Un-Treated Papers for the Bookkeeper Process (aging conditions–70 'C, saturated R. H.)

	Fold endurance (double fold with 0.5 kg)	
Days of exposure	Untreated	Treated
0	1,406	1,390
7	933	1,160
14	619	969
21	410	809
28	272	676

SOURCE: Bookkeepw.

The VPD process is the simplest of all the processes but cannot really be considered a mass deacidification in the same scale as the other three systerns. The VPD process does not deposit an alkaline buffer. Protection lasts only as long as the packets continue to give off vapors. The deacidification may not be permanent since the byproducts are volatile and under certain conditions (i.e., humidity and temperature) may revert back to acids. The data relating to the uniformity and completeness of treatment is anecdotal.

Cyclohexylamine carbonate will react with some inks, colors, and plastic covers, and therefore will require preelection before treating. Cyclohexylamine carbonate will also leave an odor in the books. The use of charcoal in the packets reduces the odor only slightly.

costs

It is difficult to obtain uniform cost estimates for comparing the various processes. Most of the detailed estimates have been independently prepared by the developers of each process and certain major cost categories are not always included. Three types of costs are important: first, the capital cost of a facility to treat a certain number of books; second, facility operating costs per unit time (usually 1 year); finally, per-book costs with assumptions of the total number of books treated per year. These three cost types are presented separately. Because most of the data are available for pilot plant sizes (about 40,000 books per year), cost comparisons will be made only for this capacity.

Capital Costs

OTA has obtained pilot plant capital cost estimates for three processes (DEZ, Wei T'o, and Bookkeeper) from the developers of that process. (See table 18.) Conveniently, roughly similar capacity pilot plants have been designed or built for each.

Operating Costs

To compare operating costs, all important categories for each process must be considered. Since only some of the data are available from developers of each system, OTA made rough estimates of some missing items. Table 19 displays certain operating

Table 18.—Capital Costs of Alternative Systems at Pilot Plant Sizes

Pilot plant	cost ($ millions)	Books capacity/18-hr. shift
DEZ[a]		50
Design	0.6	
Construction	1.3	
Wei T'o[b] (no design breakout)	0.5	150
Bookkeeper[c] (construction only)	0.4-0.6	100

[a]Based on the actual cost of design and construction for the pilot plant @Texas Alkyls; capacity based on 55-hour cycle time may be modified depending on experiments to be performed during 1988.
[b]Based on actual costs in 1979 reported to OTA by Canadian National Archives. Other information Indicates this may also be approximately the replacement cost in 19S7.
[c]Based on Bookkeeper design and detailed cost estimate reported to OTA in October 19S7. A modification to the design in December 1987 (a closed chamber system) was reported by the manufacturer to have a lower cost.

SOURCE: Office of Technology Assessment, 1988.

Table 19.—Selected Operating Costs for Three Systems at Pilot Plant Sizes (thousands of dollars per year)

	DEZ[a]	Wei T'o[b]	Bookkeeper
Plant costs	50	100	30
Operating labor	120	80	80
Overhead and administration	30	20	20
Total	200	200	130

[a]Prorated from Library of Congress estimates for full-scale plant.
[b]From Canadian experience.
[c]From Richard Spatz estimates for plant costs and Canadian experience for other costs.

SOURCE: Office of Technology Assessment, 1988.

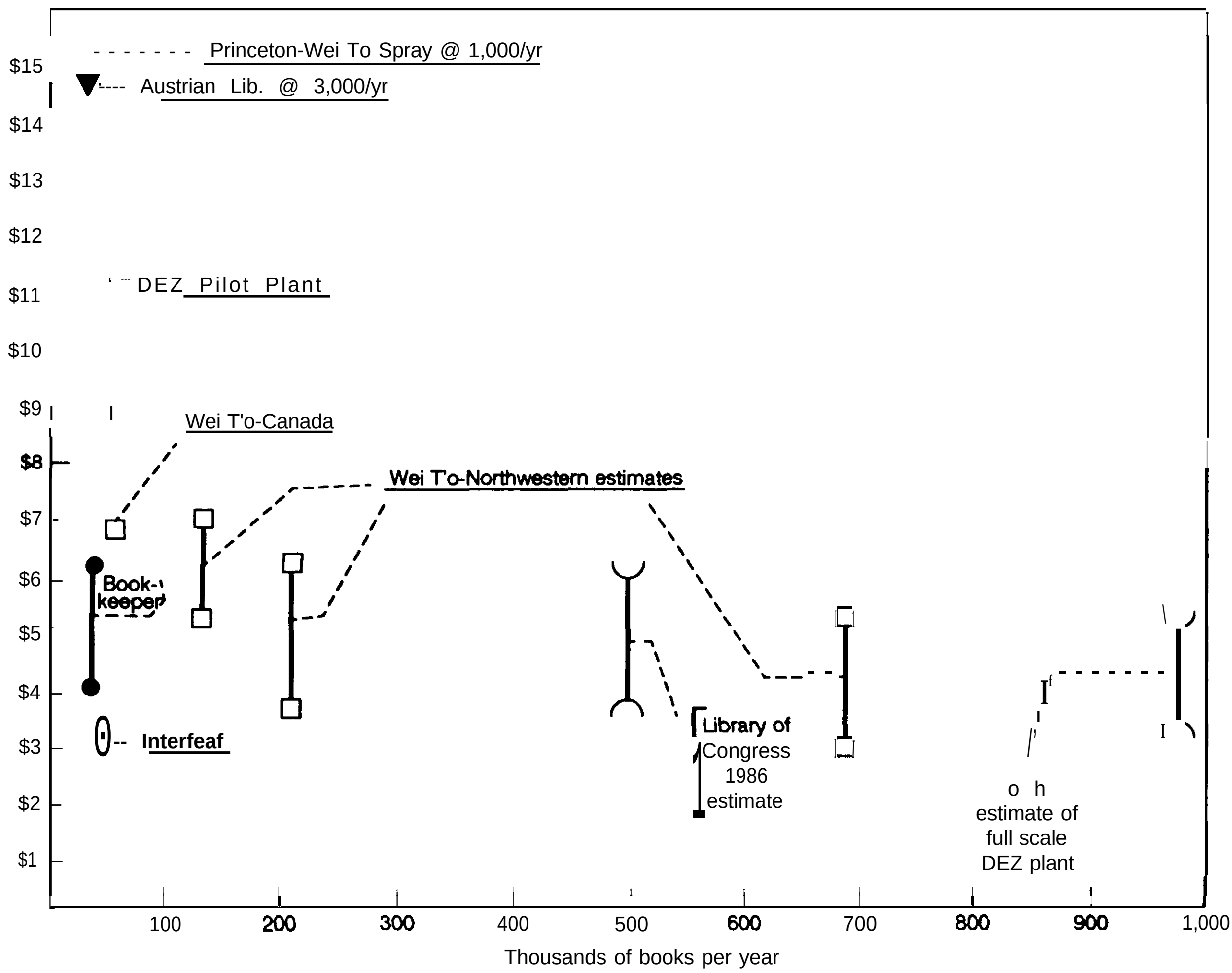
costs per year for the same pilot plant treatment capacities noted above (assume 40,000 books per year). Operating costs associated with transportation and handling of books to and from a treatment facility are *not* included because these costs can vary significantly depending on the library and the plant location as well as setup.

Per-Book Costs

Figure 25 displays deacidification costs per book from OTA estimates based on a variety of sources. OTA tried to make all costs comparable by adding similar figures for categories not supplied by others. Those costs based upon some operating experience are shown as single values; those based upon projections as +/- 20-percent range. It is clear that there are a wide range of costs for the various processes. For the 40,000 book per year pilot plant size, present indications are that the DEZ process is by far the highest cost followed by Wei-To, Bookkeeper, and Interleaf (VPD).[4] Further design, development and testing could change these costs—especially for DEZ and Bookkeeper. The much larger plants, of course, are more uncertain for final costs. Even with this uncertainty, it does ap-

[4] The cost for the VPD process is based on information from the manufacturer of a typical charge he has made in the past for treating a few thousand books at his facility.

Figure 25. -Estimates of Per-Book Costs for Deacidification by Various Processes, 1987



SOURCE: Office of Technology Assessment, 1988 pear that the DEZ process will remain the highest cost alternative.

Safety, Health, and Environmental Impact

The DEZ process does pose safety risks to the plant worker and the public. The reactivity and instability of DEZ expose the workers and the public to potential fire. The impact on health is not expected to be serious. The Library has performed a lengthy review of the health effects literature for zinc oxide and has performed a number of toxicological tests. It is also about to perform an extensive animal study to assess the risks of carcinogenicity and other health effects not documented in the literature.

Although neither the Wei T'o or the Bookkeeper process appear to pose serious safety hazards nor adverse health effects, no formal assessments or literature reviews have been made. Therefore, OTA also lists their impact on health as uncertain in table 16. Fluorocarbons, used in both of these systems, can cause asphyxiation and, if decomposed, can release toxic gases. The amount of Freon 12 in the work environment at the Candanian Wei T'o facility was measured and was well below the Threshold Limit Value (TLV) set for freon. Workplace concentrations averaged from 63 to 125 ppm per volume. The TLV is 1,000 ppm per volume.[5]

Because of the uncertainty regarding future regulations on the use of fluorocarbons, the cost and complexity of both the Wei T'o and the Bookkeeper processes may increase. The fluorocarbons used in these processes can be replaced by other compounds, but both effectiveness and safety may be compromised. Substitutes with similar properties are flammable and more reactive. Ethane emissions from the DEZ process should meet existing hydrocarbon regulations. Ethane's contribution to smog and other air pollution is relatively small and will probably not be affected by any changes in these regulations.

The VPD process is a manual process and poses no safety hazards. Early in its development, however, concerns about the carcinogenicity of cyclamates were extended to cyclohexylamines. These concerns have been relaxed. The use of cyclohexylamines as rust inhibitors is extensive in England.[6] However, as with the Wei T'o and the Bookkeeper processes, no formal assessment of cyclohexylamines or the VPD process has been made. Therefore, its effect on health is also listed as uncertain in table 16.

Other Processes

OTA received limited information on several other deacidification and combined deacidification/strengthening processes. The information provided was either insufficient to analyze to the same degree as the other systems discussed, or the development of the process has not progressed far enough to be considered a viable alternative to the Library's DEZ process.

Deacidification Processes

The French process developed by the Bibliotheque Nationale uses essentially the same chemistry as the Wei T'o system. A pilot-scale plant began operation at the Conservation Center at Chateau de Sable during the fall of 1987 with a capacity of 300 books per 8-hour shift. The system has been described as using more solvents than the Canadian system, which may result in problems with certain inks running.[7] The Bibliotheque Nationale plant is still in its trial period as of this writing, but the developers report analyses show uniform treatment and good alkaline reserve, The developers also plan to conduct their own evaluation during 1988.[8]

The Kathpalia process uses ammonia in a sealed chamber. The process has been used in India by the National Library and National Archives as early as 1955. Current costs are about 30 cents per volume that is 4 inches thick in a chamber that holds 350 volumes.[9] Major criticisms of this system are

[5] J. M. Elgie, Dupont of Canada, Ltd., Technical Report Prepared for the National Archives of Canada, Apr. 2, 1980.

[6] Personal communication with a Robertson lab representative.

[7] Jean-Marie Arnault, "Mass Deacidification in France, " paper presented at the Preservation of Library Materials Conference sponsored by CDNL, with the cooperation of IFLA and UNESCO, Vienna, April 1986, referenced in G. M. Cunha, Mass Deacidification for Libraries, Library Technology Reports, May-June 1987, p. 383.

[8] Jean-Marie Arnoult, Bibliotheque Nationale, letter to Peter Johnson, Nov. 16, 1987.

[9] Yashpal Kathpalia letter to Peter Johnson, Dec. 12, 1987.

that it does not provide an alkaline reserve and bad odors are associated with the process. Kathpalia responds to these criticisms by stating that a reserve is not really needed if the books are stored properly and even if they do need to be retreated, the process is so inexpensive it is not a problem. He also responds that odors can be eliminated with adequate ventilation. OTA has not examined this process in detail, but conventional wisdom is skeptical of amine-based processes. Detailed evaluations of the current condition of books that were treated with this process back in the 1950s might be enlightening.

Combined Deacidification/ Strengthening Processes

The Austrian National Library is currently deacidifying and strengthening its newspaper collection. The process it has developed is an adaption of the aqueous deacidification process using calcium hydroxide as the neutralizing and buffering agent. In addition, methyl cellulose is added to the solution. The methyl cellulose precipitates out of solution and acts as a laminate to strengthen the paper. After removing the cover, a block of newspapers is immersed in the solution and then shock frozen at –40 °C. The frozen block of paper is then freeze-dried and rebound. The Austrian Library is treating about 50 blocks of newspapers per 5-day week.[10]

The German Library in Leipzig is also developing a process based on the aqueous calcium hydroxide solution deacidification system. The German process adds a carrier to the solution that deposits new cotton cellulose fibers, actually putting a new layer of paper over the old.

The British Library is developing a process that would strengthen paper by grafting a polymer onto the paper's cellulose chains. Papers are exposed to a monomer mixture that impregnates the paper. The paper is then irradiated with low-intensity gamma rays, causing the monomer to attach to the cellulose and to polymerize into chains that link with other cellulose fibers.[11] The process can also be used to deposit an alkaline buffer by choosing an appropriate base monomer as co-monomer. The British process is entering engineering development. Current work is focused on a liquid system. After this has been refined, a large-scale system is planned that could treat 100,000 to 200,000 books per year at a preliminary cost estimate of $5 per book.[12] Recent developments on this process were presented by Dr. Clements in a paper titled "Emerging Technologies in Paper Strengthening: Development and Scale-Up of Graft Co-polymerization Technique, " at a Conference in West Berlin in October 1987, organized by Internationale Arbeitsgemeinschaft der Archiv, Bibliotheks-und Graphikrestauratoren.

Just when OTA was completing this report, another U.S. firm from Linden, New Jersey announced a new process they had tested, ' 'the Booksavers MGD process. It is a system based on existing industrial processes for mass sterilization of medical products and food ingredients. Ammonia gas, moisture, and ethylene oxide are introduced into a vacuum chamber to react with paper components to form long-chain amines within the cellulose matrix of the book paper. According to the developers, acids are permanently neutralized, the amines provide an alkaline reserve and crosslinking between the reaction products strengthens the paper.

Based on developer claims, the process would appear to have the potential to deacidify, strengthen, and sterilize books with a gaseous process and overcome the safety issue for DEZ and the preelection issue for the Wei T'o process. Tests performed by the developer show increased fold endurance, uniformity of treatment based on pH measurements, stability of pH change, and an alkaline reserve in treated books ranging from 0.85 to 2.14 percent, depending on the pH of the treated book. The developers have a facility that they claim can be modified to treat 20,000 books each day at a cost of $2 to $3 per book. They also claim that preelection is not required and the books can be treated in sealed cardboard cartons.[13] None of these claims has been subjected to independent analyses and OTA has not been able to evaluate these claims.

[10] For a more detailed description of this process see Otto Wachter, "Techniques for Preserving Newsprint, " in G. M. Cunha, Mass Deacidification for Libraries, Library Technology Reports, May-June 1987, pp. 445-458.

[11] D. W. G. Clements, "Emerging Technologies—Paper Strengthening, " *Restaurator*, vol. 8, 1987, pp. 124-128.

[12] D. W. G. Clements letter to Peter Johnson, July 31, 1987. The cost estimate covers direct costs, overhead, and depreciation of capital.

[13] Vladimir Zwass letter to Peter Johnson, Dec. 18, 1987.

ALKALINE PAPER PRODUCTION

One potential long-term solution to the problem of acid deterioration of books is to print books on acid-free, or alkaline, paper. 14 Alkaline paper has a much longer life than acid paper. If all new books were printed on alkaline paper, then it would not be necessary to deacidify them. This section discusses the current status of alkaline paper production and the advantages and disadvantages associated with converting from acid paper production.

Status

Major differences between alkaline and acid paper include the type of sizing that is used to prevent ink from penetrating through it and the type of filler used to make the paper smooth and opaque and to improve printing properties. For alkaline paper, two main types of synthetic sizing materials are used that are active on the alkaline side: alkyl-ketene-dimer (AKD) and alkenyl succinic anhydride (ASA). Calcium carbonate is generally used as the filler and alum is not required as a coreactant. These materials have become popular in Western Europe and have a strong foothold in the U.S. market. But, most paper in the United States is made using rosin/alum sizing and kaolin clay filler, which results in acidic paper.

Calcium carbonate has been used in printing and writing paper production since the 1950s. It was introduced not for its advantages to longevity, but as a way of using byproducts from a pulping process. Calcium carbonate adds brightness and helps promote good print quality through improved ink receptivity. Calcium carbonate is a natural pH buffer to acidic materials. Papers made with it have an alkaline pH, i.e., above 7. Since calcium carbonate will decompose under traditional acidic papermaking conditions, it must be employed in an alkaline papermaking system.

There is general agreement that the market for acid-free paper is growing, although it remains small relative to total book paper production. Estimates published during the 1980s for the proportion of alkaline paper out of overall book paper range from 15[15] to 25 percent. 16 One source projected a 10-percent increase in the share of alkaline paper through the 1990s.[17]

According to the American Paper Institute, there are no statistics breaking out the volume of alkaline paper produced, or the number of companies producing it. About 30 companies make book publishing paper. Thirteen of these produce 20,000 tons/year or more, including three that produce 100,000 tons/year or more. Two out of the top three companies have alkaline systems. There are about 200 corporations operating a total of about 1,000 pulp and paper mills in the United States today. Therefore, the 30 companies making book paper represent 15 percent of the total number of paper companies.

Alkaline paper is more firmly established in Western Europe (with the exception of Scandinavia) than in the United States. The percentage of acid-free book paper production in Europe is probably about 50 to 65 percent of the total. Among other reasons for the growth of alkaline paper making there, Europe has large easily mined chalk (calcium carbonate) deposits while clay is limited and relatively expensive.

Advantages of Alkaline Paper to Paper Manufacturers

Alkaline paper can provide several cost-saving advantages to paper manufacturers for raw materials, pollution control, maintenance expenses, and production volume. However, these advantages are highly specific to individual plants. Other advantages relate to paper quality and longevity. While

I+ The Council on Library Resources Committee on Production Guidelines in its 1982 report "Book Longevity" has recommended that several categories of books be printed on acid-free paper. These were primary printed sources, important works of fiction and nonfiction, collected editions, bibliographies, guides to collections, yearbooks, gazetteers, scholarly periodicals and monographs, dictionaries, encyclopedias, and other reference books. Categories that need not be on acid paper were also suggested to be textbooks, anthologies, vanity publications, athletic and political hagiography, popularizations in all fields, novelizations of films, formula novels, and most paperbacks.

15 Chandru J. Shahani and W.K. Wilson, "Preservation of Libraries and Archives, *American Scientist*, vol. 75, May-June 1987, pp. 240-251.

16 Library of Congress, "Paper Durability for Book Longevity," Technical Note 116, Herald of Library Science, vol. 22, July-October 1983; and Committee on Production Guidelines for Book Longevity, Council on Library Resources, Inc., "Book Longevity," 1982.

17 Conversation with Tom Lord, James River Corp., July 31, 1987.

most manufacturing costs (e. g., labor) are comparable for acid and alkaline paper of similar quality, some manufacturers find cost advantages in switching to alkaline processes.

Cellulose fiber is the most important raw material in paper. For mills that have to buy fiber on the open market in particular, the price of fiber is an important cost in paper manufacturing. Because of the chemically reactive synthetic sizing, alkaline paper is stronger than acid paper. Thus, manufacturers can lower the fiber content of paper while increasing filler and ash content, and get equivalent strength for less cost.[19] Estimates of savings range from $25 to $45 per ton for some grades. While not all types of paper can use increased amounts of filler, more than half the market could benefit. The incentive to lower fiber content is increasing, as the price of fiber is rising.[20]

This potential cost advantage of the alkaline process is probably the most important factor in increasing the market share of alkaline paper. However, its impact may be limited. Large paper manufacturers usually own their own pulp mills, often located close to the paper mill. The cost of fiber for these manufacturers is low. Therefore, the economic advantage for conversion would be less than for many smaller firms. In some cases reduced fiber content may be a disadvantage to manufacturers, as discussed later.

Another cost savings for raw materials applies to some specialty papers. Calcium carbonate can substitute for titanium dioxide, which is more expensive and more difficult to obtain.

Pollution control costs may be lower for alkaline production. Effluent from acid paper making has to be adjusted by adding alkaline materials. No adjustment is needed for effluent from alkaline processes, which comes out with pH near neutral. Also, alkaline effluent has less biochemical oxygen demand (BOD), reducing the BOD load at waste treatment plants.[21] Another environmental advantage for alkaline paper making is the reduction of specific pollutants of concern generated in acid paper making, such as aluminum.[22]

The importance of these benefits varies. Pollution abatement advantages are usually substantial for the large plants that produce the bulk of U.S. paper. Most large U.S. paper plants have pulp mills and wastewater treatment facilities co-located onsite. Pulp mills produce far more effluent than paper manufacture, and if a company can treat pulp mill effluent, it has little problem treating paper plant effluent.

Some maintenance costs may be lower for alkaline production. To reduce water consumption, most paper making companies recycle the water used in manufacturing. When water from acid processes is recycled, alum buildup is experienced, and the system needs to be purged periodically. Compared with the alum/rosin process, less alkaline filler is lost during paper making.

Whether switching to alkaline processes brings cost advantages depends on the specific circumstances of the manufacturer. One manufacturer reported that while the problems encountered are different, there were no major advantages to alkaline in terms of their cleaning needs. Some firms would need to modify their bacteriological control systems if they were to convert to alkaline paper production.

Decreased water consumption is another possible benefit, to the extent that alkaline processes enable increased recycling.

Alkaline paper processes are less corrosive than acid processes to paper-making machinery. For some manufacturers the advantages of this apply mainly to older non-stainless steel equipment. However, the corrosion advantages of alkaline processes are tangible even for stainless steel.

Some mills can produce greater volumes of alkaline paper than acid paper per unit of time because of differences in water retention. For example, if a mill is drier limited, it can make it go faster and boost production.

Other potential advantages of alkaline production relate to paper quality and longevity. Alkaline

[18] Jay W. Brown, ' 'The Once and Future Book: The Preservation Crisis, Wilson Library Bulletin, May 1985, pp. 591-596.

[19] Conversation with Terry Norris, July 7, 1987, Jan. 11, 1988.

[20] Conversation with Robert Olsen, P. H. Glatfelter, July 9, 1987.

[21] Conversation with Robert Olsen, P. H. Glatfelter, July 9, 1987.

[22] Conversation with Tom Commeau, Champion International, July 15, 1987.

paper has greater strength than acid paper. The alkaline process also produces advantages in other areas of quality: alkaline paper is brighter, more opaque, and smoother, which improves print quality and color reproduction. It also reduces mottling. These potential benefits depend on paper grade, the quantity of filler used, the specific type and quality of the calcium carbonate pigment used, and other material and equipment changes.

Although the market for alkaline paper is not particularly strong at present, some in the paper industry believe the advantages of alkaline paper in longevity will become increasingly important to publishers and their clients.

Disadvantages of Alkaline Paper to Paper Manufacturers

Despite the advantages listed above, there are important obstacles to increasing the role of alkaline paper in paper manufacturing including low demand and the costs of conversion. Growth in the share of alkaline production will be slow until these obstacles are lessened.

The market for alkaline paper, while growing, is not strong enough to motivate major increases in production by paper manufacturers. In general, most U.S. publishers and their customers do not see sufficient advantages to alkaline paper to cause them to select it over comparably priced acid paper.

Publishers are constrained by lack of demand from commercial booksellers. Whether or not a book is printed on alkaline paper is not an important consideration for most buyers at the retail level .23 The main demand for acid-free books comes from libraries, which account for about 10 to 15 percent of total publishers' sales.[24]

The effects of low levels of demand are compounded by the size of the book paper market. Book paper is a small part of total writing/printing paper production, and an even smaller part of total paper production. In 1986, about 78 million tons of paper and paperboard were produced, out of which 20.5 million tons were printing/writing paper. Book paper accounted for 950,000 tons, less than 5 percent of printing/writing paper and less than 2 percent of total paper production.[25]

Most of the paper used in U.S. books comes from companies whose main products are not book paper. Perhaps one-quarter of book paper comes from companies whose main product is such paper, and who might be expected to be more sensitive to whatever demand exists for paper longevity. The remainder is manufactured by companies with diversified product lines. In many cases, book paper accounts for only a small fraction of the total sales of paper makers. It appears that there is little incentive on the production side to change manufacturing processes at this time.

Switching to alkaline production can be costly for manufacturers, and switching to alkaline paper brings costs to users. Many producers and customers do not want to take the time and effort to adapt their processes to something new. Since a top management commitment to invest in the "learning curve' of a new process would be needed, paper manufacturers would require a similar commitment from their customers.

For manufacturers, switching to alkaline paper may involve substantial retrofitting costs. Depending on the mill, new chemical preparation systems will be required, incorporating different internal sizing, mixing, and storage equipment. The cost may be over $1 million for even a medium tonnage paper mill.[26]

Another factor affecting cost is how calcium carbonate is obtained. Some manufacturers have chosen to build a plant onsite to make calcium carbonate precipitate, thereby gaining good quality control—important in assuring that calcium carbonate particles will be uniform in size. However, such plants are expensive, about $10 million. The other route is to buy fine ground calcium carbonate direct from quarries, with some sacrifice in quality. Depending on transportation costs, buying from quarries can be cheaper than building a plant.

[23] Jay W. Brown, "The Once and Future Book: The Preservation Crisis, " Wilson Library Bulletin, May 1985, pp. 591-596.
[24] Lauren Jackson-Beck, "The Problems of Preservation: Can Librarians and Publishers Solve Them?" *Collection Budding,* summer 1985, pp. 21-25.
[25] Conversation with James Hutchison, American paper Institute, July 14 and 23, 1987.
[26] Conversation with Tom Commeau, Champion International, July 15, 1987.

Alkaline sizing materials are also $1.00 to $1.50 per dry pound more expensive than acid sizing and it is therefore slightly more expensive ($0.50 to $1/ton) to make alkaline paper water resistant.[27] Although to some the increased expense of water resistance could be an important impediment, for most these costs are not significant obstacles to the spread of alkaline paper-making.

Probably the most important disincentives to the spread of alkaline paper-making are the general problems of changing over to a new system. Mills operate on modest margins and high production rates, and taking the time to learn new methods is costly. Similarly, customers used to acid paper may have to make adjustments in dealing with a new product. For example, some dyes that work with acid paper do not work well with alkaline paper. Also, alkaline paper has different "rUnnability" characteristics than acid paper-that is, it feeds through machinery differently. Industries making envelopes, tablets, etc. have had to change some of their manufacturing procedures.[28] In particular, operators have had to slow down the machinery that converts paper from rolls to single sheets and other products. It is likely that this problem will be resolved within a few years, this has affected the acceptability of alkaline paper to some important categories of users.

Adjustments in processes (e. g., in altering dyes) are relatively easy. With adjustments, alkaline paper is equal to or better than acid paper for most uses. Still, without a cost differential in favor of alkaline paper, there is little incentive for end users to take the effort and cost of dealing with conversion problems—and little incentive for paper manufacturers to risk sales by introducing alkaline in place of acid paper.

As mentioned above, one of the main selling points of the alkaline process is its potential for saving costs through fiber reduction. This also has a down side. Many customers of paper manufacturers (e. g., makers of envelopes) sell large quantities of waste paper to recyclers, often deriving substantial revenue. Rising pulp prices have made waste paper more attractive as a raw material.[29] There is concern by these customers that decreasing the fiber content of the paper they use will make the waste paper less attractive to recyclers. In turn, paper manufacturers considering alkaline processes are concerned that their clients might prefer acid paper for this reason.

[27] Conversation with Jay Vreeland, S.D. Warren, July 9, 1987.

[28] R.G. Johnson, "U.S. Alkaline Fine Papermaking To Experience Slow But Steady Growth," *Pulp and Paper,* December 1986, pp. 66-67.

[29] *Paper Chemicals Markets in Europe* (New York, NY: Frost & Sullivan, Inc., 1982), p. 32.

DISCUSSION

No mass deacidification systems are operating or are being built, designed, or planned on the scale envisioned for the Library's DEZ full-scale facility (over 1 million books per year).

One mass deacidification pilot plant using a Wei T'o system is in operation at the National Archives of Canada. This plant has been in operation for 7 years and treats about 40,000 books per year—roughly the capacity of the Library's DEZ pilot plant built for engineering testing in Texas. The "Bookkeeper" process has also been developed and a pilot plant system has been designed, The system has yet to be built but it would have a capacity on the order of the DEZ and Wei T'o pilot plants. Other systems of a much smaller scale are in operation (a Wei T'o spraying system at Princeton and an aqueous deacidification and strengthening system in Austria), the French are testing a small pilot plant based on the Canadian design, and the English have just begun to design a small-scale system that would both strengthen and deacidify books, but this is still at a very early stage of development.

Only two processes, Wei T'o and the Bookkeeper have had sufficient development at the scale required by the Library to merit consideration as options to the DEZ process at this time.

There have been no independent tests or evaluations of the cost and effectiveness of these processes. All data and estimates have been developed by the firm or organization that is promoting the process (including the Library). Without some independent analyses with standard test materials and procedures, a definitive comparison of the processes cannot be made.

In general, all of the processes neutralize the acids present in the paper. Each of the developers present data that indicate their process can extend the life of a book by roughly the same amount (two to five times), based on fold endurance after accelerated aging. Other supporting analyses are limited mainly to pH measurements and alkaline buffer contents, resulting in a limited amount of information on which to assess the processes.

With this in mind, a qualitative evaluation of the advantages and disadvantages of the three principle mass deacidification processes follows.

The DEZ system is capable of treating books with a high degree of uniformity. The zinc oxide buffer can be controlled and leaves the paper relatively neutral regardless of the paper's initial acid content. It is compatible with most other book materials, especially inks and pigments, and requires little or no preelection. It is also capable of treating other formats. Health and environmental impacts of the system are considered to be minimal, but are currently or will soon be investigated in greater detail.

The key technical disadvantage of the DEZ system is that safety is a critical issue in the operation of the plant and requires added costs to manage. There are small but serious risks to plant workers and equipment and to a limited extent, the public (i.e., during the transportation of DEZ to the plant). It is also capital intensive and requires a relatively large initial investment.

The Wei T'o system is based on a chemistry that is accepted in the preservation community. The pilot plant in Canada has been in operation for 7 years. Unfortunately, development of the system has not progressed much during that time, although the operation of the plant is routine. The Wei T'o system is currently moderate in cost and investment. It is relatively safe compared to the DEZ plant. Although the health impacts of the process are not considered to be problem, they have not been formally assessed.

The principal disadvantage of the Wei T'o process is that its solvents are not compatible with a number of common book materials and artifacts (i.e. stamp inks, label adhesives, certain pigments, and certain plastic laminated book covers). The Canadian operation rejects 20 to 25 percent of the books sent for treatment. The amount of alkaline buffer appears to be less than that deposited by the DEZ process and varies with the concentration of the solution and the initial acid content of the papers. There are no data describing the uniformity of the treatment. One book picked at random during an OTA visit showed non-uniform treatment of the pages. The amount of fluorocarbons released during the total process is below current regulations. However, the uncertainty about future regulations makes investment and operating costs more uncertain.

The Bookkeeper process is the simplest of the three. It has the shortest cycle times, requiring no drying as do the other two processes, and capital investment would probably be low. Because of the chemicals it uses, compatibility with inks, colors, etc. is not expected to be much of a problem, although not enough tests have been conducted to determine what, if any, preelection is necessary (e.g., plastic Covers may be a problem as with the Wei T'o process). Tests by the developer have shown that treatment can be uniform throughout the book and page. The alkaline buffer does not depend on the moisture or initial acid content of the paper. Health impacts are not considered a problem, although no formal assessment has been made.

The primary disadvantage of the Bookkeeper process is that it relies on its alkaline reserve to neutralize the paper over time. Although fold endurance tests after aging show results similar to those of the DEZ process, the depletion of the alkaline reserve would be expected to be faster. Uncertainty about future regulation of fluorocarbons makes capital and operating costs uncertain. Also, the level of development of the total system is behind that of the DEZ and the Wei T'o systems.

The use of alkaline paper in books is not expected to grow significantly in the near future. The advantages and disadvantages of switching to alkaline paper varies from producer to producer and publisher to publisher. The major factor inhibiting a wider conversion is that book paper makes up a small percentage of the paper market, and the library community and those interested in preservation make up an even smaller percentage.

Since there are no reliable data to estimate the trends in the use of alkaline paper, OTA cannot make a quantitative estimate of costs to switch to alkaline paper. It would be desirable, however, to compare alkaline paper production costs to future deacidification costs for some category of books or materials that end up being valuable in library collections. Prior to making such estimates, however, the library community would need to select and agree on those categories. While such an approach would not have any effect on the brittle book problem of today, or even a few years from now, it might result in substantial savings in the long run.