The Use of Fumigants in Archival Repositories

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This article is intended as a state-of-the-art compilation and is based primarily upon secondary sources. Many of the chemicals referred to in the processes described in it are highly toxic and must be used with extreme caution and great care. The strictest safety procedures and other measures to ensure adequate ventilation must be incorporated in all fumigation techniques.

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HUMAN HISTORY, AS THE ARCHIVIST MUST DEAL WITH IT, is a fragile thing. Heir to the depredations of fire, flood, and man-made catastrophes, the paper record may also be the subject of more insidious injuries caused by those organisms which regard it as food or as a nesting material.

More than 70 species of insects and 100 species of fungi are known to attack archival and library materials. Of the insect predators, cockroaches, silverfish, termites, woodworms, bookworms, black beetles, booklice, and crickets predominate as stack pests in North America and Europe. These creatures find especially attractive the cellulose content of paper, and the starch paste, animal glue, and leather components of bound volumes. Damage from insects may range from superficial attacks made on starch paste by booklice to the overwhelming destruction of the body of a document or book made by a severe termite or woodworm infestation.[1]

The mold species of most concern to the archivist are of the *Ascomiceti* and *Deutermiceti* families. The primary effect on paper of the growth of these microbiological organisms is the softening of fibrous components due to cellulose ingestion. In addition to the weakening effect that accompanies such softening, damage to documents may occur in the form of unsightly stains deriving from a secretion of colored pigments characteristic of many of these fungoid species, or as a result of the mechanical bonding of adjoining pages that is often a by-product of the growth cycles of certain types of mold.[2]

The impact that insects and mold growth make on particular archival holdings

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[1] Fausta Gallo, "Biological Agents Which Damage Paper Materials in Libraries and Archives," in *Recent Advances in Conservation* (London: Butterworth, 1963), pp. 55, 57–58.

[2] Ibid., p. 58.

or manuscript collections is usually in direct proportion to the environmental controls exercised in the repository. The proper design of archival facilities, especially in subtropical areas, is of extreme importance in excluding insects. Even in temperate zones, the degree to which temperature, humidity, and air movement or circulation are controlled in storage areas will often determine the degree to which insects and mold are a problem. Mold, for example, will not actively propagate on paper and leather unless the relative humidity is at least 72.8 percent.[3] Hydrophilic insects such as silverfish, moreover, can be discouraged by the maintenance of 50 percent relative humidity in a well-lit storage area where the air freely circulates.[4]

When maintenance of stack temperature between 60–65°F. and relative humidity between 45–50 percent is beyond the resources of an archival facility, and especially when that facility is housed in a structure not specifically designed for the storage of paper materials, the archivist must be prepared to deal effectively with the threat of mold or insect infestation. This is especially true for repositories which regularly receive materials previously stored in basements, attics, or other dead storage areas, or materials from other areas where proper storage conditions have not been maintained.

Recent conservation literature is rich with data on fumigation. Although some new techniques involve the use of sophisticated electronic apparatus,[5] recommended practices in general continue to center around a variety of chemical treatments. Whatever infestation problem they are specific for, such treatments, for use in archival or library situations, ought to meet three basic criteria: they should be rapid and powerful in their fumigant action, be low in toxicity to humans, and have no adverse effects on the constituent elements of the material being treated.[6]

Although most recommended compounds meet the first criterion of effective fumigant action, most of them would constitute a positive menace in the hands of archivists inexperienced in the ways of these chemicals or ignorant of the potential consequences of their careless use. Even the careful archivist, closely following the directions of recognized specialists in the field, should be wary. Let us take the case of thymol, one of the most universally recognized specifics for the treatment of mold and mildew. Writing in the *Conservation of Library Materials,* George Cunha notes that

> Thymol, although not lasting, is an effective, easy to use, general purpose sterilizer. Mildewed materials can be exposed to the vapors in simply constructed fumigation cabinets in which the chemical is melted in watch glasses over 25-watt bulbs. The cabinet is designed to accommodate loose papers, books, manuscripts, maps, and prints. Thymol is toxicologically safe, but should be used with caution because it dissolves some inks and attacks paint and varnish. Thymol and other fungicides are known to be more effective if

[3] S. S. Block, "Humidity Requirement for Mold Growth," *Engineering Progress at the University of Florida,* October 1953, p. 287.

[4] Gallo, "Biological Agents," p. 55.

[5] See, for example, A. P. Petrova-Zavgorodnyaya and Z. A. Zagulyaeva, "The Effects of High Frequency Electromagnetic Fields on Paper Destroying Mold Fungi" and Z. A. Zagulyaeva, "The Lethal Effects of High Frequency Currents on Cellulose-Destroying Mold," in A. P. Zagulyaeva et al., *New Methods for the Restoration and Preservation of Books and Documents* (Jerusalem: Israel Program for Scientific Translations, 1964), pp. 2–7, 22–23.

[6] Gallo, "Biological Agents," p. 59.

mildewed paper that has subsequently been dried out is humidified before the chemical treatment.[7]

Elsewhere, Cunha continues that "thymol in heavy doses is safe on any library material not coated with oil paints or vårnish, except palm leaves."[8] Sir Hilary Jenkinson, on the other hand, discussing thymol some thirty-seven years earlier, reported that "the only thing to be said against it is that its complete harmlessness to materials has not been proven: it has in fact at times a softening effect on vellum, size, and glue the reason for which has not, I believe, been explained."[9] As to thymol's toxicological safety, a standard manual on the subject of chemical toxicity, *Dangerous Properties of Industrial Materials,* rates thymol as an irritant and as moderately hazardous, meaning that exposure to the chemical, if inhaled, "may involve both irreversible and reversible changes not severe enough to cause death or permanent injury."[10]

Another method suggested by Cunha for the use of thymol as a moldicide is the interleaving of sheets impregnated with 10 percent thymol in alcohol, between old infested books and loose papers.[11] Jenkinson, however, reported that "vellum bindings in contact with heavy thymolized paper became—very alarming—covered with a sticky exudation."[12] There are also hazards connected with the use of *alcohol* as a dissolving medium. We can probably assume that Cunha is suggesting the use of denatured ethyl alcohol rather than methyl alcohol which is "moderately hazardous" when inhaled or absorbed through the skin in large enough quantities, and is similarly "moderately hazardous" when inhaled.[13]

In fairness to Cunha, it must be pointed out that in his appendix on "Precautions in the Use of Pesticides" he does suggest precautions, such as the use of protective clothing, gloves, and a respirator, that may provide adequate personal protection from most toxic hazards.[14]

For the purposes of this article, Cunha's treatment of thymol and the conflicting statements on the subject are being used merely to illustrate some of the difficulties that archivists must be aware of when dealing with fumigants. The potential toxicity of such chemicals cannot be emphasized too heavily. The annual death toll in the United States from the misuse of insecticides is estimated to be 200. For every fatality, moreover, there are 100 poisonings that do not end in death.[15]

Before attempting the use of any fumigant, the archivist should gain an awareness of its toxicity and the toxicity of any solvents that may be used in the

[7] George Martin Cunha and Dorothy Grant Cunha, *Conservation of Library Materials: A Manual and Bibliography on the Care, Repair, and Restoration of Library Materials,* 2d ed., vol. 1 (Metuchen, N. J.: Scarecrow Press, 1971), p. 147.

[8] Ibid., p. 353.

[9] Hilary Jenkinson, *A Manual of Archive Administration,* 2d ed. rev., reissue (London: Percy Lund, Humphries, & Co., Ltd., 1965), p. 224.

[10] Newton I. Sax et al., *Dangerous Properties of Industrial Materials* (New York: Van Nostrand, Reinhold, Co., 1975) p. 1170.

[11] Cunha, *Conservation of Library Materials,* p. 147.

[12] Jenkinson, *A Manual of Archive Administration,* p. 224.

[13] Sax, *Dangerous Properties,* p. 909–10.

[14] Cunha, *Conservation of Library Materials,* Appendix N, pp. 351–54.

[15] Robert L. Metcalf and William Luckmann, eds., *Introduction to Insect Pest Management* (New York: John Wiley and Sons, 1975), pp. 249–50.

process. The archivist should consult one of the standard references on the subject, the *Dangerous Properties of Industrial Materials,* mentioned above, or the *Merck Index.*[16] The proper application devices and safety equipment for the specific process chosen should be procured, and the individual responsible for the actual fumigation procedure should receive instruction. Both the individual doing the fumigation and his immediate supervisor should be aware of the symptoms of accidental exposure and the emergency procedures to take should it occur. The archivist should also thoroughly understand and adhere to the specific regulations promulgated by both federal and state environmental protection agencies governing the use of pesticides.

In cases in which the application of even small quantities of a highly toxic chemical are being considered, professional exterminators must be consulted. Even when a compound is rated as only moderately toxic, it might be well for individuals inexperienced in handling chemicals to consult the professionals in the field. Finally, it should be remembered that EVEN WHEN A FUMIGANT IS LISTED AS HAVING LOW TOXICITY, IT CAN BE EXTREMELY DANGEROUS IF MISUSED.

Insecticides

Archival fumigants may be divided into three basic classes: insecticides, moldicides, and general fumigants. Insecticides recommended for use in archives are generally applied in the area of contaminated material rather than upon the documents themselves. These pesticides include, among others, arsenic trioxide, dieldrin, lindane, naphthalene, paradichlorobenzene, pyrethrum, and silica aerogels.

Arsenic trioxide had been used effectively in the control of the termite *Nasutitermis exictiosus* H. Only 1.70 grams blown into the holes drilled in the nest or sprinkled on its ruins will eradicate entire colonies of this subterranean species.[17] Since arsenic is highly toxic and is a recognized carcinogen, however, application should be left to the professional exterminator.[18]

Dieldrin is recommended as a specific for the control of silverfish. Fumigation is accomplished through the use of paper sheets coated with a 0.3 to 0.4 weight for weight deposit of the chemical. These sheets are marked "dieldrin treated—do not handle" and placed, as warranted, in infested archival boxes. Developed especially for use in libraries and archives by the Division of Entomology of the Commonwealth Scientific and Industrial Research Organization (Canberra), this technique has numerous advantages including the extraordinary residual life of the chemically-treated sheets, which is said to be as long as ten years.[19] Since this chemical is rated as highly toxic when inhaled, or absorbed through the skin, the dieldrin treated sheets should be prepared by professional chemists under controlled conditions. The concentration of this substance in the working areas, moreover, should not exceed the established Threshold Limit Value (TLV) of 0.25 milligrams per cubic meter of air (25mg/m^3).[20] Information was not avail-

[16] *Merck Index,* 8th ed. (Rahway, N. J.: Merck and Co., 1968).

[17] J. J. Svent-Ivany, "Identification and Control of Insect Pests," in *Conservation of Cultural Property With Special Reference to Tropical Conditions* (Lausanne, Switzerland: UNESCO, 1968), p. 62.

[18] Sax, *Dangerous Properties,* p. 419.

[19] Svent-Ivany, "Insect Pests," p. 55.

[20] Sax, *Dangerous Properties,* p. 18.

able in the conservation literature concerning the physical effect of an ambience of this fumigant on surrounding paper documents.

Lindane (1,2,3,4,5,6-Hexachlorocyclohexane) is noted as an effective fumigant when used against cockroaches and silverfish. Available in powder, dust, or as a liquid, it is applied in building crevices and similar insect hiding places. Since it is known to have adverse effects when directly applied to paper or ink, application in the liquid form should be by brush rather than sprayer in areas immediately adjacent to archival materials.[21] This chemical is classified as moderately toxic and its TLV, in working areas, has been established as 0.5mg/m^3.[22]

Naphthalene is a specific against most archival insect pests, particularly beetles. It is applied in a sealed box by exposing the infested material to the fumes of this volatile chemical at the rate of 47 grams per cubic foot of air. The chemical is placed in a steep-sided dish and left in place for ten days to two weeks.[23] Naphthalene is a skin irritant and is moderately toxic when inhaled or absorbed through the skin. Its maximum TLV in working areas is 10 parts of vapor per million parts of contaminated air by volume, at 25°C. and 760mm. HG pressure (10ppm.) and/or 50mg/m^3.[24] Although no specific data as to its effect on archival materials has been found by this writer, its use is recommended by reputable conservators.[25]

Paradichlorobenzene is one of the most universally recommended general insecticides and is a specific for booklice and beetles. Applied like naphthalene and in similar proportions, it is less noxious to humans, rated moderately toxic as an irritant and only slightly toxic when inhaled. Its workroom TLV is 74ppm. or 450mg/m^3.[26] As with the previous chemical, no specific test data on paradichlorobenzene's effect on archival materials is available, but the substance finds general acceptance among paper conservators and archivists. Since it does not destroy insect eggs, treated materials should be examined *at least* during the year after fumigation to determine if reinfestation has occured.[27]

O-isopropoxy phenyl methyl carbamate (Baggon) is a "highly toxic carbamate insecticide"[28] that is said to be of value in the control of cockroaches. The conservator recommending its use specifies dilution to "an 0.5% solution that can be brushed over cracks and other places of intrusion."[29] In this writer's opinion, this chemical's toxicity suggests it is best left to application by experts.

Pyrethrum is noted as effective against the cockroach, cricket, and silverfish. It is a common ingredient in household pesticides. Pyrethrum I is a viscous liquid, moderately to highly toxic when inhaled, and may provoke serious reactions in

[21] Ann F. Clapp, *Curatorial Care of Works of Art on Paper,* 2d ed., rev. (Oberlin, Ohio: Intermuseum Laboratory, 1974), p. 34.

[22] Sax, *Dangerous Properties,* pp. 19, 802.

[23] Clapp, *Curatorial Care,* p. 39.

[24] Sax, *Dangerous Properties,* pp. 20, 498–99.

[25] Including such conservators as Ann F. Clapp in *Curatorial Care,* p. 29, and J. J. Svent-Ivany in "Identification and Control," p. 65.

[26] Sax, *Dangerous Properties,* pp. 18, 624.

[27] See especially Yash Pal Kathpalia, *Conservation and Restoration of Archive Material* (Paris: UNESCO, 1973); Clark W. Nelson, "Archival Preservation," *Drexel Library Quarterly* (January 1975), p. 91; H. J. Plenderleith, *The Conservation of Antiquity and Works of Art,* 2d ed. (London: Oxford University Press, 1971), p. 64; and D. B. Wardle, *Document Repair* (London: Society of Archivists, 1971), p. 16.

[28] Sax, *Dangerous Properties,* p. 438.

[29] Clapp, *Curatorial Care,* p. 34.

persons allergic to the chemical. It has a workroom TLV of 5mg/m^3. Pyrethrum flowers is a moderately toxic powder which affects allergic individuals less severely than pyrethrum I.[30] Both chemicals are applied in structural cracks and around the base of shelves. As with so many other recommended insecticides, no test data analyzing the effect of these chemicals on archival materials are available in the conservation literature.

Silica Aerogel is a finely powdered microcellular silica foam that destroys roaches, termites, and other soft bodied insects mechanically through its action in the destruction of the fatty layer of the insect's body. It may be scattered in cracks and crevices where infestation is suspected.[31] Also used as a general purpose food additive, the only toxic consequence of its use is the potential for development of silicosis if the chemical is inhaled in large quantities. For this reason, the material has been assigned a TLV of

$$\frac{30\text{mg/m}}{\text{percent of quartz} + 3.}$$ [32]

In addition to the powdered and liquid insecticides described above, several gaseous compounds have been used as insecticides in both archives and libraries. Among the more common of these are aluminum phosphide (trade name Phostoxin) and sulfuryl fluoride (trade name Vikane). Because of their extreme toxicity, archivists might do well to avoid their use.[33] The application of such compounds is probably best left to professionals.

Moldicides

Visual observation of mold infection on a document or volume is not necessarily evidence that the microbiological organisms present are active. As has been noted earlier, if the relative humidity in the immediate area of a document or volume is kept below 72 percent, growth will generally be successfully inhibited. When in evidence in a single document the mold may be simply brushed off, with due care being taken not to smear the stain. The location of this infested document should be noted and it should be checked periodically over the next year to make sure that no reinfestation has taken place.

If reinfestation does occur, the application of a suitable fumigant is called for. In instances where the observed mold infestation is not isolated to a single box, it might be well to test the repository as a whole through the exposure in various places in the stack area of petri dishes containing a culture medium.[34] If such tests prove positive, area fumigation and subsequent reevaluation of environmental controls are necessary.

[30] Sax, *Dangerous Properties,* pp. 21, 1069.
[31] Fausta Gallo, "Biological Agents," p. 59.
[32] Sax, *Dangerous Properties,* p. 23.
[33] Letter with enclosure of an annotated first draft of this paper from Frazer Poole to C. F. W. Coker, March 8, 1977, p. 1.
[34] For methods of mold culturing, see Roger Heim, Françoise Flieder, and Jacqueline Nicot, "Combatting Moulds Which Develop on Cultural Properties in Tropical Climates," in *Conservation of Cultural Properties With Special Reference to Tropical Conditions* (Lausanne, Switzerland: UNESCO, 1968), p. 43; and Clapp, *Curatorial Care,* p. 72.

Moldicides are applied either directly to the infected material or to an entire area where contamination is suspected. Suggested area disinfectants include thymol and trichlorethane, and lauryl-dimethyl-carbethoxymethyl ammonium bromide. These are fumigants that should be applied only when the infected area can be successfully sealed off from inhabited parts of the facility. Individuals who normally work in the area being treated must not return to that location until all moldicide vapors have been dispersed and the room has been thoroughly aired.

Thymol in conjunction with 1,1,1, trichlorethane is suggested for fungicidal fogging. In the proportion of one pound of thymol to one gallon of trichlorethane, the compound is said to be sufficient for an area of 20,000 cubic feet.[35] The hazard rating for thymol has been discussed; 1,1,1, trichlorethane is rated as moderately toxic when inhaled or absorbed through the skin.[36]

The quaternary ammonium salt, lauryl-dimethyl-carbethoxymethyl ammonium bromide (trade name Cequartyl BE), prepared in a 5 percent solution with denatured alcohol, is recommended for use in area fumigation for mold in the proportion $5cm^3/m^3$. It may be applied using an air compressor and spray gun with a fine mesh grill or, preferably, with a "swing foot" type of atomizer. The compound is said to be irritating to the mucous membranes, and use of a suitable respirator is recommended.[37] The conservation scientists who advocate use of this treatment indicate that it has been applied successfully in archives and libraries for a number of years; others, however, have indicated a problem with ink adhesion upon exposure to the chemical and suggest also that it may adversely react with cellulose.[38]

For direct application to infested documents, the most recommended of the various moldicides suggested include orthophenyl phenol, salicylanide, and thymol.

Orthophenyl phenol (trade name Topane, Dowcide 1) has been suggested as a moldicide for both leather bindings and paper. As a leather fungicide, it is applied in a 2–5 percent solution in alcohol or distilled water. As a paper moldicide the chemical is used to treat interleaving or wrapping paper in a 10 percent aqueous solution.[39] Since its volatility is low, treated papers can be used as active fumigating agents for six months or more without replacement. The chemical is rated as a slightly toxic irritant.[40]

Paranitrophenol is another phenol compound occasionally recommended for use as a fungicide. A minor ingredient in "Leather Protector," a well known proprietary leather preservative,[41] this chemical may leave a greenish tinge on paper[42] when used in excess. It is rated as a highly toxic substance.[43]

Salicylanide (trade name Shirlan) and sodium salicylanide are said to be useful

[35] For detailed procedures for the use of this compound, see Peter Waters, *Procedures for the Salvage of Water-Damaged Library Materials* (Washington: Library of Congress, 1975), pp. 12–13.

[36] Sax, *Dangerous Properties,* p. 1186.

[37] Heim et al., "Combatting Moulds," p. 44.

[38] Mariagrazia Zappala, "Some Aspects of the Chemical Research in the Instituto Di Patologia de l Libro," in *Conservation of Paintings and the Graphic Arts* (London: International Institute for Conservation of History and Artistic Works, 1972), pp. 998–99.

[39] Clapp, *Curatorial Care,* p. 32.

[40] Sax, *Dangerous Properties,* p. 1018.

[41] Clapp, *Curatorial Care,* p. 33.

[42] Kathpalia, *Conservation and Restoration,* p. 53.

[43] Sax, *Dangerous Properties,* p. 972.

as fungicides on both leather and paper. These moderately toxic chemicals are used in 0.5–1 percent solutions in leather preservatives.[44] Caution must be observed in their usage since they are known to have undesirable effects if applied in excessive quantities.

Thymol, mentioned earlier in this article, may be used by vaporization, applied directly to the infected paper in a 10 percent solution in denatured ethyl alcohol, or applied through the interleaving of sheets treated in the 10 percent solution. Many conservators suggest the use of vaporized thymol in a home-made fumigation chamber. These chambers vary in size from a cabinet 5 x 2½ x 4½ feet to a room-size chamber, 15 x 6 x 8 feet. The vaporization is accomplished by heat from a light bulb surmounted by a watch crystal or other glass container, or from a rheostat-controlled heating element fixed to the bottom of the chamber.[45] Sources differ as to the amount of chemical to be used, the degree to which it should be heated, and the ler.gth of time necessary for a killing exposure. Plenderleith suggests 50gms. to a cubic meter of air. The chemical is to be heated by a 40 watt bulb for two hours after which the material is to continue being exposed for an additional 24 hours, undisturbed. This process, it is suggested, should continue for a period of fourteen days.[46] Yash Pal Kathpalia, in *Conservation and Restoration of Archive Materials,* maintains that 120 grams is the recommended dose for a cubic meter of air but claims success with 20 gms. and a single hour exposure.[47] D. B. Wardle, in *Document Repair,* suggests 25 gms. as the proper amount of chemical to use,[48] while Anne F. Clapp, in the *Curatorial Care of Works of Art on Paper,* suggests a four-day exposure to the vapors.[49]

Problems with the use of thymol include the fact that it has been known to attack some book glues, it dissolves some inks, and it may leave residues on parchment and, if overheated, on paper as well. Direct application or interleaving has been known to discolor documents. As previously noted, the chemical is considered to be moderately toxic if inhaled.

In addition to those currently acceptable chemicals described above, a much wider variety of moldicides have been suggested in the past for use in the fumigation of books and papers, but have been found by some conservation scientists to have adverse effects on archival and library material. Included among these are formaldehyde, boron decahydrate of triethanolammonium diborolactate, pentachloro-phenol, and sodium orthophenyl phenate (Topane w.s.). Formaldehyde, recommended by Plenderleith and others[50] as a gaseous fumigant, is said to cross-link cellulose as well as to harden leather, and it should be avoided.[51] Boron decahydrate of triethanolammonium diborolactate, used in at least one instance as an area moldicide by the French National Archives,[52] can cause paper to soften.[53] Pentachloro-phenol is a strong acid and therefore may also adversely affect archival materials. Sodium orthophenyl phenate (Topane

[44] Clapp, *Curatorial Care,* p. 32.
[45] Plenderleith, *Conservation of Antiquities,* p. 61; and Kathpalia, *Conservation and Restoration,* p. 53.
[46] Plenderleith, ibid.
[47] Kathpalia, *Conservation and Restoration,* p. 54.
[48] Wardle, *Document Repair,* p. 15.
[49] Clapp, *Curatorial Care,* p. 39.
[50] Plenderleith, *Conservation of Antiquities,* p. 60; and Heim et al., "Combatting Moulds," p. 43.
[51] Poole to Coker letter, March 8, 1977, p. 1. Plenderleith himself points out the hardening effect on leather.
[52] Heim et al., "Combatting Moulds," p. 44.
[53] Page 9 of enclosure with Poole to Coker letter, March 8, 1977.

w.s.), noted in one source as "the most generally effective fungicide available for use in records offices and libraries,"[54] in addition to being highly toxic[55] is distinctly colored and can produce severe stains on paper.[56] Undoubtedly many of these moldicides can be used safely if they are applied under the supervision of a conservation scientist; their use should not, however, be attempted by the archivist.

General Fumigant Gases

Various toxic gases have been developed as general fumigants to destroy vermin, insects, insect eggs, mold, and even bacteria. Of the many such chemicals available, those used most commonly by archival repositories are ethylene oxide and methyl bromide.

The largest majority of repositories using general fumigant gases rely on ethylene oxide. Tested by the U.S. National Bureau of Standards in 1935, an ethylene oxide-carbon dioxide mixture was found to have no deleterious effect on the eight commercial paper stocks subjected to experimental exposure, and no subsequent damage has been reported in its use on printed paper, manuscripts, leather, and cloth bound books.[57]

The simplest of the class of cyclic ethers known as eposides, ethylene oxide is explosively flammable when exposed to air in its pure form[58] and is therefore generally made available in one of the following dilute compounds: 12 percent ethylene oxide and 88 percent dichlorodifluormethane (trade name Ucon 12) by weight (Oxyfume 12), 20 percent ethylene oxide and 80 percent carbon dioxide by weight and gas volume (Oxyfume 20), 30 percent ethylene oxide and 70 percent carbon dioxide by weight and gas volume (Oxyfume 30), and 10 percent ethylene oxide and 90 percent carbon dioxide by weight and gas volume (Carboxide).

Other factors being equal, the higher the concentration of ethylene oxide to inert gas, the shorter the time necessary for fumigation. Thus, with Oxyfume 30, a two to two-and-a-half hour exposure would insure sterilization at 130°F.; using Carboxide, a four-hour exposure at the same temperature would be necessary. On the other hand, Oxyfume 20 and 30 are flammable and Carboxide is not.[59] Oxyfume 12 is recommended as the optimal fumigant by two of the leading manufacturers of vacuum fumigation chambers.[60] Since this chemical compound combines its nonflammability with having a large proportion of ethylene oxide, it would indeed seem to be an ideal fumigant. Unfortunately, the Ucon 12 which renders the mixture especially safe is a fluorocarbon and hence is poten-

[54] Maurice F. Bond and A. D. Baynes-Cope, "Technical Notes: I Fungicides," *Journal of the Society of Archivists* (April 1970), p. 52.

[55] Sax, *Dangerous Properties,* p. 1016.

[56] Page 11 of enclosure with Poole to Coker letter, March 8, 1977.

[57] Charles G. Weber, Merle B. Shaw, and E. A. Back, "Effects of Fumigants on Paper," *Journal of Research of the National Bureau of Standards* 15 (September 1935): 271–75. Also letter to Richard Strassberg from Frazer G. Poole, assistant director for preservation, Library of Congress, September 19, 1975.

[58] "Ethylene Oxide Sterilization: A Current Review of Practices," *Journal of Hospital Research,* (February 1969), p. 8.

[59] *Gas Sterilization: A Modern Method for Modern Materials,* a promotional brochure for Linde Gas Sterilants, products of Union Carbide Corporation, pp. 5–10.

[60] Letters to Richard Strassberg from Sandra Cunningham, Kewaunee Scientific Equipment, September 18, 1974; and Richard Cimaroli, Vacudyne Altair, November 25, 1975.

tially damaging ecologically when vented into the air. Archivists who are environmentally concerned might wish to use the less efficient carbon dioxide mixture, Carboxide, which costs, incidentally, about one quarter as much as Oxyfume 12.

Most archival repositories and libraries fumigating with ethylene oxide have installed vacuum fumigation chambers which allow optimum gas penetration of the materials being fumigated. The typical mechanism consists of a steel chamber with a hermetically sealable door, an electrically heated gas volatizer, a vacuum pump, a gas cylinder, tubing, and controls. The operation is rather simple. After the chamber is sealed, the air is pumped out and fumigant gas, volatilized through heating, is bled into the chamber. After the required exposure time, which depends on the gas mixture and the nature of the infestation,[61] residual gas is pumped out, air is again bled into the chamber, and the unit can be opened.[62]

Such chambers are available in a variety of standard sizes and also can be made to order. The smallest chamber currently on the market is the Vacudyne Vacufume 18 fumigator which has an 18 cubic foot capacity and is 2′7″ wide, 3.5″ deep and 5″ high. Larger chambers can hold up to several hundred cubic feet of archival materials.[63]

Before purchasing any vacuum fumigation equipment, archivists would do well to seek answers to the questions that follow. Is the venting, which is mandatory with such installations, in keeping with local anti-pollution and life-safety statutes? What are the economics of large versus small chambers? Who will train archival personnel in the safe operation of the equipment? What kinds of security against accident and tampering does the unit offer? Can the manufacturer guarantee quick service and is there a service contract available? Is the fumigant to be used obtained easily locally?

Because of the high costs involved in the installation of vacuum systems, consideration should be given to the cooperative use of fumigating facilities. Is there a system already in the area that can be sub-leased? A mobile fumigating chamber such as is maintained by the New England Document Conservation Center might prove attractive for consortium use.[64] Finally, it may be possible to do away with chamber use altogether and occasionally fumigate with ethylene oxide.

Allan Claghorn of the Linde Division of Union Carbide, the major manufacturer of ethylene oxide gas, has reported on the experimental decontamination of surgical instruments using an ethylene oxide mixture contained simply in a plastic bag and vented under a fume hood. The elementary procedure he out-

[61] The destruction of mold, for example, requires twice the exposure as that for the destruction of insects.

[62] Vacudyne Altair, Specifications, Vacufume-18 Document Fumigator. JA2.001–174. n.d.

[63] Four U.S. manufacturers answered inquiries about the availability of fumigation chambers. They are: Fey Steel, Box 477, Mars, Pennsylvania 16046 (telephone 412–625–1551); Kewaunee Scientific Equipment Co., Special Products Division, Adrian, Michigan 49221 (313–263–5731); John Mohr and Sons, 3200 E. 96th Street, Chicago, Illinois (312–768–0650); and Vacudyne-Altair, 375 E. Joe Orr Road, Chicago Heights, Illinois 60411 (312–364–2200). Of the four, Kewaunee and Vacudyne-Altair seem to have had the most experience with archival type installations, with Kewaunee noting fourteen installations in archives, libraries, and museums in the U.S. and Canada, and abroad.

[64] George Martin Cunha and Norman Paul Tucker, "Mobile Units," in *Library and Archives Conservation* (Boston: The Library of the Boston Athenaeum, 1972), p. 199.

lines, which involves the use of a vacuum pump as well as the hood and the usual gas apparatus, might well be investigated by conservation scientists for its possible application in the fumigation of small quantities of archival materials. It must be emphasized here that such experimentation should be carried out only by trained personnel.[65]

Similar experimentation might be in order for so-called tent fumigation. Such fumigation involves the use of a simple tent of six mil polyethylene. "Snakes" made of plastic tubing three to four inches thick and filled with sand or water, are laid around the tent to seal it. A vent is made for replacement of the air when the gas is introduced and for gas release after fumigation. This technique has been used successfully to fumigate foodstuffs and the like, but experimentation is needed to see if it will meet the needs of archivists.[66]

Methyl bromide is a general fumigant gas, capable of destroying vermin, insects, insect eggs, and some mold. Although nonflammable in undiluted form, it appears to be distinctly inferior, having only one-tenth of ethylene oxide's sterilizing efficiency. Methyl bromide may be applied in a chamber, in a plastic tent similar to that described above, or under proper supervision it can be used as a room fumigant. Once felt to be a most efficient sterilizer, it is being largely supplanted by ethylene oxide.[67]

As well as following the manufacturer's instructions about the length of exposure necessary for the particular kind of "kill" desired, the user would be wise to test the actual killing effectiveness and penetration of the various fumigant gases. The tests can be made through the use of a chemical indicator or culture strips. Prior to fumigation, these strips are generally inserted in several places throughout the collection between the sheets of the boxed or bound material. The General Electric Space Division, for example, routinely tests, through the exposure of several spore strips containing a resistant strain of *bacillus subtilis* var *niger*, the effectiveness of the ethylene oxide and vaporized thymol fumigation treatment given to water-damaged books and papers which are freeze-dried in their space chamber. These strips are then recovered from the treated materials and incubated in trypticase soy broth for two weeks at 37°C. and then examined for growth. When no growth is evident, which is generally the case, the treatment is deemed successful.[68]

Conclusion

It is obvious that sophisticated techniques exist for the destruction of virtually every insect and microbiological enemy of archival material. Many of these techniques can be applied at a relatively reasonable cost and without the use of extremely sophisticated equipment. Extreme caution, however, in the use of fumigation methods such as have been described above must be observed.

[65] Allan Claghorn, "Gaseous Decontamination of Instruments in Plastic Bags: A rationale for the use of ethylene oxide gas for sterilization, with detailed procedural instructions covering its use," *Contamination Control* (May 1967), pp. 9–12.

[66] Union Carbide Company, "How to Fumigate with Non-Flammable Carboxide Gas or Non-Flammable UCAR F892 Fumigant Gas." 8 pp. Pamphlet, n.d., p. 6.

[67] Karl Kereluk, "Gaseous Sterilization: Methyl Bromide, Propylene Oxide, and Ozone," American Sterilizer Co., reprint, n.d., pp. 107–8, 112–13.

[68] "Test for Sterility of Biological Indicators Included in Salvaged Records From Cornell University During Processing in the G. E. Space Chamber," General Electric Space Division Program Information Release, August 7, 1976.

Three French scientists, writing in the UNESCO manual, *The Conservation of Cultural Property,* present with admirable succinctness the difficulties involved in applying such techniques:

> The problem of the preservation of cultural property is clearly an extremely complex and extremely difficult one. Protective and remedial treatment to combat the many possible types of destruction may thus easily yield results ranging from excellent to disastrous. The fight against destructive agents must therefore be conducted with the utmost care, common sense, and patience. If, for example, disinfection has been badly carried out, using an overconcentration of pulverized products, or if disinfectant substances have been applied at too close a range to such delicate objects as, say, documents, the results will be bad—perhaps even catastrophic. There are all too many preservation techniques which, if misapplied, can defeat their objective completely. . . . A first precaution against mishaps . . . would be to have on the staff of all museums, libraries, archives, and services in charge of the protection of monuments, fully trained specialists in conservation techniques with the advanced professional qualifications required for the job.[69]

Should a full-time conservation specialist be beyond the purse of a particular archival institution, consideration should be given to obtaining the services of a paper conservator on a part-time or even consultant basis. Should this also be impossible, the archivist without experience in chemistry must seek the advice of a professional exterminator, making sure that those techniques proposed for application are safe for use with the archival material.

[69] Heim et al., "Combatting Moulds," p. 52.