POISONS, PLASTICS AND PAPER POTENTIALLY DESTRUCTIVE COMBINATIONS IN ARCHIVAL STORAGE

Julia Fenn
Royal Ontario Museum, Canada

Abstract

Synthetic polymers, in the form of digital media, negatives, tapes and compact disks, are now an important component of modern archival collections. They consist of many different plastics with significantly different properties. These plastics, as well as "archivally safe" plastics used for framing and storage, are often unexpectedly vulnerable to contamination from trace residues of biocides once commonly used in libraries and museums. Many of them are also susceptible to volatile degradation products from the archival collections themselves. Some of these interactions will be discussed in the context of collections management, with emphasis on avoiding incompatible combinations, identifying when a plastic has become corrosive and the advantages and limitations of scavengers and barrier materials.

Introduction

Synthetic polymers in the form of photographic negatives, gramophone records, magnetic tapes and compact disks, have become an important part of modern archives, but their remarkable growth since the 1980's has focussed attention on their poor survival rate. Information loss from disks and tapes has been unexpectedly rapid, sometimes becoming irretrievable within a decade. This deterioration of plastic archival materials has already been described in terms of the structure of the different media, the breakdown of different polymers, and the acceleration of decay by heat, light, moisture and pollution (Calmes 1992; Lindner 2000; Nishimura 1995; Nugent 1995).

The different polymers in libraries and archival collections are not necessarily compatible with one another or with traditional library materials. They emit, absorb and react to a wide range of gases including those given off by deteriorating books, bindings and parchments as well as from chemicals used for cleaning and pest control. The speed of deterioration set against the cost and labour involved in reviewing, prioritising and copying this growing body of materials means that much data is lost before it can even be examined. It is necessary to be aware of the weaknesses of these different plastics and their response to the conditions commonly present in archives and libraries, so that their usable life expectancy will not be curtailed.

Types of plastics in libraries and archives

Examples of types of plastics found in libraries and archives include, film tapes, gramophone records and compact disks and machinery for playing recordings. The next section discusses these plastics in detail.

Films and tapes

Cellulose nitrate was the first commercial plastic to have been used for archival purposes. It is best known as the substrate for 19th and 20th century negatives, and in North America it was manufactured for this purpose from 1889 to 1951 but it remained available in Europe and Asia well into the 1970's. Cellulose nitrate is a most versatile material and was also used for coated papers, pyroxylin book bindings, motion picture film, decorative embossing in albums and books, cylinder sound recordings, and as an adhesive for splicing tapes. Well-made cellulose nitrate in a cool, dark, unpolluted environment can remain stable for a very long time, but once it has decayed to the point where it begins to emit acidic, oxidising gases, it causes irreversible damage to library materials including paper, leather, adhesives, inks, many dyes, most metals and all archival plastics.

Cellulose acetate esters were the most common archival plastics for over fifty years. Cellulose diacetate and cellulose acetate propionate were introduced during the 1920's as safer, less flammable alternatives to cellulose nitrate negatives. Diacetate was also used in the 1930's for dictaphone tape, in which the data was directly embossed in grooves in the plastic tape. In 1939 cellulose acetate butyrate was introduced for x-rays and other specialist films and at the end of the war cellulose triacetate became cheap enough to replace cellulose nitrate motion picture film. It was also used as the substrate in magnetic tapes, where the information was encoded in a layer of magnetised metallic oxide particles in a polyurethane binder. Some acetate esters are more stable than others but all of them give off organic acids, most notably acetic acid which is a notorious museum pollutant. Although the organic acids given off by degrading cellulose acetate esters are weak and non-oxidising, they are nevertheless very harmful and in archives they can accelerate deterioration of cellulose nitrate, degrade gelatin emulsions, contaminate storage materials and corrode metals.

During the 1960's and 1970's polyester [poly (ethylene terepthalate)] gradually replaced cellulose triacetate as the substrate in audio and videotapes. Polyester tape was also preferred over acetate for computer tape because of its strength and resistance to moisture and most chemicals, it was nevertheless a slow transition because polyester was more expensive and not as easy to use being very springy. Modern polyester computer tapes are extremely thin and tear resistant as a result of improvements in extrusion technology and bi-axial orientation. Despite its chemical resistance, polyester can be attacked by prolonged exposure to strong, oxidising agents - such as nitrogen dioxide given off by cellulose nitrate. The three types of film are not compatible and should not be stored together; simple methods for distinguishing between substrates made from cellulose acetate, nitrate and polyester have been described by Nishimura (1995).

Gramophone records and compact disks

Early 20th century "plastic" gramophone records were usually made from the natural resin shellac, with a mineral filler such as slate, added to increase rigidity. Shellac is not aggressive but it embrittles with age. Other less commonly used materials included phenol formaldehyde (Bakelite™) and highly vulcanised rubber, commonly known as Hard Rubber (Vulcanite™, Ebonite™). Hard Rubber emits sulphur compounds harmful to metals, paper and leather and is especially bad for photographs. Phenol, otherwise known as carbolic acid, is emitted by phenol formaldehyde plastics, but also by disinfectants and biocides. It is harmful to cellulose nitrate and is incompatible with tricresyl phosphate, (an additive often present in cellulose acetate), causing breakdown into phosphorous compounds including phosphoric acid. Phenol is a contaminant which is often overlooked in museums and archives.

During the 1950's, long-playing records made from highly plasticised PVC [poly(vinyl chloride)] sometimes co-polymerised with poly(vinyl acetate), were introduced and quite rapidly replaced shellac. Small 45rpm disks, also introduced during the 1950's, were similarly made from PVC or occasionally polystyrene, but by the 1980's gramophone records became obsolete and were superseded by tapes and the emerging compact disks. It is unwise to stack records together in close contact because the plastics are often incompatible. Polystyrene and rubber interact with one another and to a lesser extent with plasticised PVC. The additives in plasticised PVC sometimes constitute more than one third of the weight of the plastic and many of them migrate and condense as oily films on adjacent materials, causing discolouration, distortion and trapping dirt. This occurs throughout the life of the plastic. Sleeves are not adequate barriers against the transmission of plasticisers even when the original acidic paper has been replaced with polyethylene or polypropylene because both absorb oils readily. When the polymer itself breaks down, very aggressive emissions of hydrogen chloride gas are given off while the plastic slowly disintegrates. PVC is not limited to gramophone records, during the late 1960's, one type of microfilm made from a very unstable poly (vinyl chloride) was notorious for corroding its way through metal storage cabinets (McCrady 1991).

Some of the large-format, first generation compact disks were made from acrylic, [poly (methyl methacrylate)], but polycarbonate was found to have superior rigidity and impact resistance. The injection-moulded, flat disk is embossed on one side with pits encoding the data, which are then coated with a thin, reflective layer of aluminium or occasionally gold, and protected with a varnish usually an acrylic or epoxy resin. Acrylic and polycarbonate are not inherently harmful plastics, but they are very vulnerable to both damage and contamination from volatiles, including acetic acid and many biocides. Both plastics absorb water vapour when humidity is high, resulting in slight swelling which, although unnoticeable to the human eye, can cause enough distortion across the disk to interfere with the laser reading at the outer edges. Other archival plastics prone to absorb sufficient moisture to cause distortion and swelling are cellulose nitrate, cellulose acetate and some formulations of polyurethane binding media. As a general rule, plastics become more susceptible to moisture as they age so humidity control in archives is crucial.

The housing for videos, tape cassettes and floppy disks, is usually a polystyrene blend such as SAN [styrene-acrylonitrile] or ABS [acrylonitrile butadiene styrene]. Jewel boxes for compact disks are moulded from unblended polystyrene and are extremely brittle. Abrasive polystyrene powder can be shed from any cracks onto the disk, so they are considered unsuitable for long-term storage. Some archives have replaced them with tough ABS or polypropylene cases designed so that the disk can be removed without flexing. Polystyrene-based plastics are not chemically harmful to other archival plastics unless there is a high level of free styrene monomer, which is a solvent for many plastics. Although the monomer is not usually released unless the plastic is heated above its softening point (80°C), some residual monomer may remain after manufacture, which can migrate out of the plastic. Non-food grade polystyrenes, such as cassettes and jewel boxes, tend to have higher levels of residual monomer. Because styrene monomers are very reactive they are used as initiators in the production of many plastics, so styrene emissions are not restricted solely to polystyrene blends.

Machinery for playing archival recordings

New electronic equipment, with acrylic screens, PVC coated wire and housing made from poly (phenylene oxide) or polystyrene blends, is likely to emit oily additives and reactive monomers, giving a noticeable “plastic” smell; such emissions can promote stickiness in magnetic tape. Old equipment, kept because it is needed for playing early formats, may have parts made from vulcanised rubber, chlorinated rubber, urea formaldehyde, acetate esters and phenol formaldehyde, all of which off-gas readily, especially if the equipment heats up during use. Reading and copying images can put the machinery at risk as well as the information media. Volatile corrosives such as formic acid, acetic acid, nitrogen dioxide, sulphur dioxide, phenol and oily plasticisers given off by both the media and by the equipment itself, are harmful to the metal parts and may attack even tough nylon gears.

This brief summary does not take into account experimentation and entrepreneurship in the plastics industry. Items were sometimes made from completely different plastics in order to reduce costs, to avoid infringing another manufacturers patent, or to get rid of bulk lots, intended for another purpose. Many of these inappropriate uses were discontinued after a short time but may be present in collections.

Vulnerability of archival plastics

Physical vulnerability

Most film and sound recordings are much more vulnerable than plastics in social history collections because of their thin cross-section, large surface area and fragile coatings, but much more is required of them: they have to be strong enough to withstand the physical stress of being repeatedly played or copied, and the information has to be readable.

Polymer breakdown and loss of additives affects size, shape and physical integrity. Any change in dimensions or shape has serious repercussions if the item no longer fits the equipment required to play it, for example if film has shrunk the sprockets do not match, and if it is too brittle it cannot sustain the required tension. At least one surface is usually the information carrier, so that even superficial surface damage, especially if it is chemical damage, may obliterate the data, and invalidate the whole item. In those with a layered structure, data loss can result from failure in the substrate, in the information layer, or in the adhesion between them. Since the different layers are made from different polymers, they can be expected to age unevenly.

Vulnerability to solvents

Plastics, as a group, are very susceptible to damage caused by all volatiles, for example, solvents, water vapour, and gaseous air pollution, and each polymer is sensitive to a different range of volatile materials. In concentrating on the damage caused by acids, alkalis and moisture, the role of solvents on plastic deterioration is sometimes neglected. Vapour-phase solvents should be considered as a serious indoor pollutant in any area where plastics are stored, they are not limited to monomers and plasticisers from the plastics themselves, but may also come from cleaning products, from leather dressing on book bindings, from biocides and from paints and glues used during renovations to storage areas.

Most archival plastics are thermoplasts, that is, they soften with heat and can be reformed in a new shape. Solvents have a similar effect in that they allow the plastic to soften, then to reform as the solvents evaporate. In the vapour form, they may not actually dissolve plastics but the imperceptible swelling and softening can have a disastrous effect on data, for example in vesicular tapes, where information is encoded directly into the plastic and will be lost as it reforms. Prolonged exposure to solvent vapour, even at low levels, encourages polymers to relax back into their prestretched state. In bi-axially oriented tapes, this results in reduced flex strength, chemical resistance and causes severe shrinkage. Modern computer tapes are so thin with such dense information to the extent that very little dimensional change causes data corruption.

All plastics, even thermosets, deform under pressure, and absorbed solvents aggravate this tendency. Poorly wound reels of film and unsupported disks or gramophone records, deform faster in the presence of solvent vapours. It should be noted that a plastic item could be deformed by solvents to which the polymer itself appears to be impervious, if its additives swell or migrate. Since the additives modify the properties of the plastic, their loss has serious repercussions; usually increasing sensitivity to heat, light, moisture or acid hydrolysis, and affecting strength, size, transparency, flexibility and permeability.

PVC is especially vulnerable because it is soluble in a wide range of volatiles. PVC gramophone records become especially vulnerable to stylus damage in the grooves, especially when played on original equipment with its comparatively heavy arm and coarse needles. Polyurethane binders are also miscible with many solvents, which encourages “sticky shed” a condition in which the binder, with the magnetised particles containing the data, are wiped off the tape as it is played.

Polymers which are glasslike at room temperature, such as cellulose nitrate, cellulose acetate, polystyrene, poly (methyl methacrylate) and polycarbonate, may develop tiny cracks (crazing) after absorbing solvent vapours. Each plastic has its own range of sensitivity to different solvents. In transparent plastics, crazing becomes visible as a grey or silvery haze which can interfere with laser reading, or make the glazing in framed documents seem dirty. Visible crazing may not appear until a long time after exposure, but weakening and embrittlement can occur well before any cracks appear, creating a security issue in display cases or glazed frames which are intended to be impact resistant.

Crazing is less an issue of high vapour concentration, than of stress. Highly stressed plastics will craze at low exposure levels. Although stress can be induced by tension, pressure or repeated flexing, it is usually an inherent vice incorporated during manufacture. Early polycarbonate disks were often exceptionally sensitive to solvent-induced stress crazing and even modern compact disks can be highly stressed if they have been cooled too quickly in the mould.

Some organic acids such as, acetic, formic and carbolic acids are solvents for plastics such as polystyrene. This increases their potential for destroying plastics because they can initiate crazing, deformation and softening as well as acid hydrolysis. At the same time they make any plastic which has absorbed them into a potentially corrosive plastic. Contamination of those plastics which are commonly recommended as safe museum storage materials is not usually taken into account, which is unfortunate considering how often, storage and display materials are re-used. Experiments at the Royal Ontario Museum demonstrated that acrylics (Plexiglas™; Perspex™) polycarbonate (Lexan™; Tuffak™), silicone and polystyrene could all be permanently contaminated by exposure to acetic and formic acid even at low levels. The contaminated plastics remained corrosive to metals even after thorough washing and seven years of continuous ventilation whereas the same plastics exposed to nitrogen dioxide and nitric acid vapours, which are not solvents for those plastics, could be washed off and had no long lasting effect (Fenn 1995a).

This has extremely serious implications for archival materials made from these polymers. Acetic acid and other organic acids are pervasive in archival storage because of the amount of acidic paper, glues and wood composites as well as cellulose esters, in libraries. Contaminated storage items can be thrown away, but information carriers that are contaminated become more vulnerable themselves and more expensive to maintain if they are to be prevented from damaging other archival materials.

Vulnerability to biocides

Libraries and archives have a long history of biocide use because books and documents are so vulnerable to mould and pests, as a result, archival plastics are frequently exposed to pesticides used to protect other parts of the collection. Damage caused by baits, sprays and powders is usually limited to areas of direct contact with the biocide, but fumigants and aromatic repellents such as camphor, are more pervasive and potentially much more harmful.

Many of the studies of commercial fumigants, have dealt with retention and toxic by-products in disposable plastic packaging, rather than with long-term degenerative effects on non-disposable plastics. As a result there is very little hard evidence, and degeneration in archival or museum plastics is rarely attributed to commercial fumigants unless there has been an immediate noticeable effect such as yellowing.

Methyl bromide fumigations are known to make rubber and elastomers vulcanised with sulphur, smell strongly of volatile sulphur compounds, especially after several exposures. The odour is extremely persistent, taking years to dissipate. There is also a belief that methyl bromide fumigation accelerates the degradation of cellulose nitrate. This is based on unverified oral history after several museums, including the Royal Ontario Museum, observed sudden deterioration in artefacts made from cellulose nitrate, which had not been noticed before the pieces were fumigated. Although it is perfectly feasible that methyl bromide did accelerate decomposition, the case is still unproven because it is one of the characteristics of this particular polymer to breakdown suddenly with little visible warning.

Ethylene oxide has been used a great deal in libraries and archives because it kills mould as well as insects. Unacceptably high levels of ethylene oxide can be retained in archival materials and in motion picture film (Hengemihle, Weberg and Shahani 1995), also in plastics containing certain common phthalate plasticisers, and it is a solvent for poly (methyl methacrylate) (Eckhardt 1973). Toxic halohydrins with a slow evaporation rate can form in halogenated plastics such as poly (vinyl chloride) (Eckhardt 1973; Florian 1987), and possibly in plastics with bromine compounds from previous methyl bromide fumigation (Scudamore and Heuser 1971). There is no record of whether the halohydrins cause long-term damage to the affected plastics. Ethylene glycol, another of the reaction products of ethylene oxide fumigation, is a solvent and a humectant and so encourages hydrolytic damage. It also softens gelatin and cellulose nitrate and disrupts phenol formaldehyde.

Volatile repellents intended for the domestic market, for example, mothballs, are potentially even more harmful than commercial fumigants, because they have been used more often and with fewer controls. Among the most common of these phase-phase biocides are paradichlorobenzene, naphthalene, camphor, dichlorvos (2,2-dichlorovinyl dimethyl phosphate in strips of poly (vinyl chloride) commonly known as Vapona™), and the fungicide thymol. All are complex solvents for plastics. At one time, they were used very freely in museums and archives and are remarkably persistent in porous materials. Fifteen years after the Royal Ontario Museum discontinued using paradichlorobenzene and naphthalene, several wooden storage cupboards had to be jettisoned because no amount of cleaning or airing could reduce the mothball emissions to levels required by North American safety standards.

The same persistence is evident after plastics have absorbed these biocide vapours. Samples of polycarbonate, polystyrene and acrylic which had been exposed to very low levels of Dichlorvos in 1993, (Fenn 1995a), still contained enough of the acidic biocide to corrode metals in 1997.

Aromatic biocide vapours are particularly destructive when used in combination; such mixtures seriously increase the risk of crazing highly stressed plastics. Mixtures also increase solvency, for example, expanded polystyrene is not damaged when packed in a crate for several weeks with pure naphthalene flakes or with pure camphor. When both biocides are present, the expanded polystyrene will slowly soften and shrink. A particularly potent combination is camphor, paradichlorobenzene and naphthalene and several commercial mothball preparations mix these three biocides. “Mixed mothball” damage has also been observed on poly (vinyl chloride) clothing (Sakata and Yamada 1979) and on natural resins (Waddington and Fenn 1988). The addition of thymol not only increases the risk of shrinkage, dissolution and crazing; it also causes yellowing, which has been attributed to photo-oxidation (Daniels and Boyd 1986). The author of this article has also observed discolouration in acrylics kept in the dark, possibly caused by halogenation of the thymol by paradichlorobenzene.

Lavender, eucalyptus, tea tree, citrus and cedar wood oils have all been used as household remedies for moths and mites. Powdered bay leaf, ginger, cinnamon, allspice and chilli have been recommended against cockroaches and all these aromatic plant materials attack plastics as can be seen in bulk food stores where the spices are unwisely stored in polystyrene or acrylic bins. Private book collections are sometimes contaminated by these or similar domestic remedies.

Vulnerability to perfumed air fresheners
With the exception of Dichlorvos, all of the repellents previously mentioned are also ingredients in commercial air fresheners manufactured for domestic use. In this form they do not come under industrial health regulations and paradoxically, although moth repellents are falling into disrepute as health hazards, the use of “air fresheners” is on the rise. Perfumed air fresheners do not remove the compounds which cause unpleasant smells, instead they mask them by emitting chemicals designed both to numb the sense of smell and to overlay the original odour. Some formulations are intended for use against the odour of mould or new paint and have been used in public buildings during renovations. Mould is more than a simple nuisance, and masking the warning odour with yet more volatiles is not helpful to the well being of either the staff or the collections. The carrier is usually a volatile oil or a wax-like substance which sublimes persistently for several weeks. Among the chemicals being emitted are solvents such as benzyl acetate, ethanol, limonene and terpinenes, all known to attack plastics. Our museum recently received a complaint about an unplayable loan of videotapes which had been stored on a shelf next to a plug-in air freshener – they were unusable but they smelt wonderful.

Although this is not by any means a comprehensive outline of problems which might be caused by volatile biocides, it is enough to indicate that chemical fumigation of plastics, or indeed archival collections in general, is undesirable. How much of the rapid decomposition of plastic information-carriers during the last two decades was hastened by fumigants will never be known.

Collections management strategies

Ideally it is best to separate incompatible materials in archives and libraries as far as possible, but it is seldom feasible. Even if film and sound recordings are stored separately from books and paper, some incompatible plastics will inevitably be incorporated in with traditional library materials because plastics have been used in books and documents for illustrations and special needs such as waterproofing, transparency or tear resistance. Protecting this sensitive and incompatible combination may seem an unmanageable task but it can be broken down into concepts which can be approached more easily.

Avoid initiating decomposition by unnecessary exposure to pollutants
An excellent start is to reach agreement with the housekeeping staff that harmful cleaners and disinfectants will not be used in the storage and display areas. This includes not only traditional materials such as ammonia and bleaches, but also some of the ecologically acceptable “green cleaners” such as vinegar (acetic acid) and concentrates extracted from citrus peel.

All archival plastics have a high static charge which attracts dust, fine grit and mould spores, especially at the low humidity levels recommended for plastics (and according to recent trends, for paper and books also). Because thin, data encoding layers are very susceptible to damage from grit and mould, it is essential to have wellfitting doors with doorsweeps, and where possible a good particle filtration system in the rooms where information carriers are stored and copied. Localised dust protection can be provided by wrapping or boxing but there is a risk of aggravating the decomposition of unstable items if the enclosure allows harmful vapours to concentrate around it. Chemical pesticides should be replaced with an integrated pest management system. For actual outbreaks, anoxic fumigation with nitrogen or carbon dioxide is currently thought to be safer than other chemicals.

Supports used to protect the collections should be chosen from materials which are not inherently unstable, have been well manufactured and do not have additives or potential degradation products which are harmful to the collections. Unfortunately the term “archival quality”, as used by some manufacturers and suppliers, does not mean that it is safe to use with archival material. This is misleading in the same way that food labelled “light” is under no obligation to be non-fattening. The Image Permanence Institute A-D strips, (paper dyed with modified bromocresol green which changes from blue through green and yellow in acid conditions), can be used to show when plastics, or other storage materials, are acidic (Anon 1995). It is a much quicker, less toxic method than using lead strips which is the traditional, low-budget method for detecting organic acids.

Plastic support materials should also be assessed in terms of properties such as absorption, permeability to gases and sensitivity to hydrolytic degradation. Very often a polymer may be chemically stable but inadequate for the requirements. For example, low-density polyethylene is very resistant to moisture absorption and to moisture-induced hydrolysis, but is a poor vapour barrier against the transmission of water vapour or other gases of small molecular weight such as sulphur dioxide or nitrogen dioxide. This was demonstrated in the teaching collection, when a small cellulose nitrate button sealed in a polyethylene bag was left lying on a compact disk, still sealed in its original polyethylene wrapping. After several months, emissions from the button had passed through both layers of polyethylene and right through the polycarbonate - which is also a poor vapour barrier - destroying a large patch of the aluminium coating on the far side of the disk. Polyethylene is often used as a barrier against water vapour and air pollution in situations when polyester would be the better choice. Baker describes the characteristics of common polymers and provides a useful system for selecting appropriate chemical and physical properties to suit different collection needs (Baker 1995).

Retarding and mitigating degradation and offgassing

Past damage is beyond control. It is as well to accept, as a collections management premise, that part of the collection will be actively degrading and that it cannot be reversed or halted. However, there are strategies for slowing the rate of decay and reducing the risk to the rest of the collection, this buys time for examination and reproduction of the data.

Low temperatures and humidity will retard hydrolysis and reduce the rate of deterioration in plastics (and other library materials), even if they are already actively degrading. The Image Permanence Institute has developed very practical guidelines on balancing temperature and humidity depending on the intended use of the collection (Nishimura 1995).

Freezing retards chemical degradation and is an effective storage strategy for negatives and film and for polystyrene plastics because they are resistant to temperature induced strain, but not all plastics or composites can be frozen safely. Acrylic, for example, has a high coefficient of expansion so is stressed by freezing, and it is also very brittle at low temperatures.

Good ventilation and filtration help to dilute emissions. Gaseous filtration is vital for storerooms containing collections which are offgassing. Removing noxious gases used to be very expensive and cumbersome, but improvements in the design of molecular filters and modification in the size and distribution of the sorbents have made commercial filtration systems more effective and affordable. Excellent information on gaseous and particulate filtration is available from ASHRAE (Robinson 1999).

The use of sorbents and scavengers within the collection can be useful in removing some of the emissions at source, but they have to be used with an understanding of their limitations or they impart a false sense of security and can even be harmful. The sorbent reservoir may be inadequate or not used effectively, for example in a passive system, the kinetic energy of the emissions may be too low to force them into the sorbent without positive pressure. Sorbents release as well as absorb, so the absorbed target acids may be displaced later by other gases, or by humidity and pressure changes.

Scavengers remove a contaminant by reacting with it to produce another substance, however the reaction product itself may be unacceptable. For example, calcium carbonate in the buffered paper which is sometimes used to interleaf negatives, reacts with the acid gases given off by cellulose nitrate and acetate to form salts which are deliquescent. They can actually accelerate damage by staining or creating a damp microclimate against the moisture sensitive film and emulsions. By removing additives, both sorbents and scavengers may reduce the stability of a plastic and hasten the end of its induction period.

Monitoring emissions

Indicator papers can be used to reveal acid emissions very early in the deterioration process so that items can be isolated before they damage other materials and while they are still in a suitable condition to be copied. Specialist indicators such as A-D strips are more useful than ordinary pH papers, which do not register well at the RH levels in archival storage rooms. It is not advisable to add a humectant, such as ethylene glycol or glycerin, to pH strips to make them register in a low humidity, because that introduces solvent volatiles into the immediate vicinity of the plastics under test. There are other risks also; the author once inadvertently made a small, but inconvenient, amount of nitroglycerin explosive by enclosing glycerol-soaked indicators with decaying cellulose nitrate.

A-D strips were specially designed to detect very low levels of weak, organic acids from acetate film but they can also be used to detect strong acid gases from PVC and cellulose nitrate, although the latter blanch the dye very quickly. For strong, oxidising emissions from cellulose nitrate, cresol red is a better indicator. It is less sensitive to interference from light or air, so it can be left with the cellulose nitrate as a continuous reference and it has a very clear colour change from yellow to bright fuchia pink. Cellulose nitrate film usually gives no visible warning that it is about to disintegrate, so a monitor showing when off gassing has begun is especially helpful (Fenn 1995b).

Identifying the actively degrading plastics, especially the most aggressive plastics, means that limited collection management resources can be deployed where the need is greatest.

References

Anon. 1995. *User's guide for A-D strips film base deterioration monitors*. New York: Image Permanence Institute.

Baker, M. T. 1995. Synthetic polymers. In: Rose, C. L., Hawks, C. A. and Genoways, H.H. (eds). *Storage of natural history collections: a preventive approach.* 1. Society for the Preservation of Natural History Collections, pp 305-326.

Calmes, A. 1992. Practical aspects of plastics found in archives. *Restaurator* 13 (1): 23-37.

Daniels, V. and Boyd, B. 1986. The yellowing of thymol in the display of prints. *Studies in Conservation* 31: 156-158.

Eckhardt, R. E. and Hindon, R. 1973. Health hazards of plastics. *Journal of Occupational Medicine* 15 (10): 808-819.

Fenn, J. 1995a. Secret sabotage: reassessing museum plastics in display and storage. In: Wright, M. M. and Townsend J. H. (eds). *Resins ancient and modern.* Preprints of the Scottish Society for Conservation and Restoration 2nd Conference in Aberdeen.

Fenn, J. 1995b. The cellulose nitrate time bomb: using sulphonephthalein indicators to evaluate storage strategies. In Heuman, J. (ed.) *From marble to chocolate*. London: Archtype, pp. 87-92.

Florian, M-L. 1987. The effect on artefact materials of the fumigant ethylene oxide and freezing used in insect control. In: I.C.O.M. Committee for Conservation Preprints of the 8th Triennial meeting in Sydney, Australia. Volume1. Los Angeles: The Getty Conservation Institute, pp. 199-207.

Hengemihle, F. H., Weberg, N. and Shahani, C.J. 1995. Desorption of residual ethylene oxide from fumigated library materials. Available: http://cweb.loc.gov/preserv/rt/fumigate/fume.html (Accessed 10 October 2001).

Lindner, J. 2000. Magnetic tape deterioration: tidal wave at our shores. Available: http://www.vidipax.com/articles/tidal.html (Accessed 15 January 2002).

McCrady, E. 1991. Kalvar microfilm – forgotten but not gone. *Abbey Newsletter* 15 (8): 121, 125.

Nishimura, D. W. 1995. Film supports: negatives, transparencies, microforms and motion picture film. In: Rose, C. L., Hawks, C. A. and Genoways, H. H. (eds). *Storage of natural history collections: a preventive conservation approach.1*. Society for the Preservation of Natural History Collections, pp. 365-393.

Nugent, W. R. 1995. Compact discs and other digital optical discs. In Rose, C.L., Hawks, C.A. and Genoways, H.H. (eds). *Storage of natural history collections: a preventive approach.1*. Society for the Preservation of Natural History Collections, pp. 401-410.

Robinson, T. J. and Ouellet, A. E. 1999. Filters and filtration. *ASHRAE Journal* (April): 65-72

Sakata, Y. and Yamada, Y. 1979. Deterioration of clothes by using mothballs. Part 1. Influence of different kinds of mothballs used at the same time onto poly(vinyl chloride) fibres. *Yamaguchi Joshi Daigaku Kenkyu Hokoku Dai*-2-bu 4/5:45 –52. (In Japanese).

Scudamore, K .A. and Heuser, S. G. 1971. Ethylene oxide and its persistent reaction products in wheat flour and other commodities: residues from fumigation or sterilisation, and the effects of sterilising. *Pesticide Science* 2: 80-91.

Waddington, J. and Fenn, J. 1988. Preventive conservation of amber: some preliminary investigations. *Collection Forum* 4 (2): 25-31.