Use of Microenvironments for the Preservation of Cellulose Triacetate Photographic Film*

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Film archivists have the option of storing film in a climate-controlled macroenvironment or in a microenvironment. This research evaluates the effectiveness of the latter to control the stability of cellulose triacetate base film in roll form. It does not consider other factors such as equipment cost, maintenance, labor expense, and accessibility. The use of vented cans to reduce the acidity of degraded film was not effective in controlling "vinegar syndrome." The addition of buffered cardboard disks to adsorb acid is not recommended. Microenvironments in which the film was previously moisture-conditioned to a low relative humidity or the addition of desiccants such as molecular sieves or silica gel did retard further degradation. The improvement obtained with molecular sieves and silica gel was owing to both their moisture adsorbing and acid adsorbing properties. However, neither material was effective at reducing the acid level of already degraded film. Macroenvironments have the potential to be of much greater benefit for film stability than the microenvironments evaluated in this study. Microenvironments are of great value when it is not possible to obtain humidity control of the storage area.

Introduction

This study investigates the impact of enclosures and various microenvironmental alternatives to macroenvironment control in minimizing degradation of acetate film base. This three-year research project was funded by the National Endowment of Humanities, Division of Preservation and Access. Microenvironment situations that were evaluated include specific enclosure designs, the use of silica gel or molecular sieves, and moisture conditioning of film rolls in sealed containers.

Background

In the 1930s the increasing use of photographic film for archival records and the expanding entertainment industry stimulated interest in the issue of permanence.[1] Cellulose triacetate (CTA) film base, first introduced almost 50 years ago[2] marked a major advance over nitrate because of its lower flammability. However, more recently the rather poor chemical stability of CTA film base has become a preservation challenge for the film archivist.[3,4] The importance of chemical stability prompted early comparative study of nitrate and acetate film supports[5] using accelerated aging. A predictive approach was developed during further studies of the stability of CTA and polyethylene terephtalate (PET).[6–8] During the past decade, the recognized chemical instability of CTA film base prompted numerous investigations.

These studies focused on the impact of either intrinsic factors (e.g., composition and nature of the plastic) or extrinsic factors (e.g., climate conditions, enclosures).

Among the various intrinsic factors, the contribution of the components of the photographic film such as the gelatin emulsion, the subbing layer (containing traces of cellulose nitrate) and the use of plasticizers in the base composition has been addressed in several papers.[9–13] The degradation mechanisms of CTA film base were reviewed and the importance of the acid-catalyzed hydrolytic mechanism was emphasized.[9,11,14–16]

These contributions added greatly to our understanding of film preservation, but they did not address the control of extrinsic factors to extend film life. Subsequent large-scale studies quantified the relationship between climate conditions (i.e., temperature and relative humidity) and chemical stability of cellulose acetate base.[8,17] These findings suggested two basic preservation strategies: The first reduces the rate of the chemical decay by controlling temperature and relative humidity.[18] The second is based on the removal of the reaction catalyst (i.e., acetic acid). Recognize, however, that the latter is only relevant once the degradation process has already started.

In practical terms, these two routes may be implemented either by controlling the macroenvironment or by creating a favorable microclimate. The microenvironment principle is that at constant temperature the permanence of photographic film depends in large measure on the nature of the air immediately surrounding it. Both options require the control of temperature, but the implementation of a moisture-controlled microenvironment might replace costly dehumidification equipment. Removal of the acid catalyst by an acid-scavenger inside a sealed film might be more effective than macroclimate measures that benefit the overall storage areas, such as increased ventilation and acid vapor adsorption (e.g., using activated char-

coal filters). Theoretically, by using sealed containers in conjunction with moisture/acid adsorbing materials or by selecting appropriate enclosures, the shelf-life of acetate film base might be significantly extended.

Several microenvironmental approaches have been suggested. More than 50 years ago the use of desiccants (e.g., activated silica gel) to control the moisture content of nonprocessed photographic film was investigated.[19] Although never widely used, this was recommended as a preservation practice for motion-picture film and procedural guidelines were provided to film archivists.[20] In 1981, the Swedish Film Institute proposed a conditioning apparatus (FICA system) that combined the merits of establishing a low moisture content in the film with cold storage temperature. This was accomplished by freezing the film after it was vacuum-sealed in moisture-proof packaging.[21] In 1993, Eastman Kodak Co. introduced the use of molecular sieves as an aid to control the so-called "vinegar syndrome."[22] Although the interest in such crystalline molecular "cages" using natural or synthetic compounds to adsorb gaseous components selectively dates[23–25] to the 1960s, their ability to trap moisture and acetic acid vapor from cellulose triacetate film base prompted a renewed interest in microenvironmental approaches for film preservation.

While the merits of low-temperature and dry conditions have been clearly identified and assessed,[18] very few studies have investigated the role of microenvironment alternatives to control acetate film stability. The considerations for enclosure design have been based either on common sense (open systems should promote acid removal from the film) or upon experimental data obtained under exaggerated situations.[9,12,14] For instance, the harmful effect of acid-trapping was documented by measuring the degradation rate of free hung film samples compared to samples kept in the worst situation—i.e., samples in vapor-proof packaging.[17] However, these data did not quantify the improvement that might be obtained under various real-life storage situations.

The main thrust of this article is to evaluate various microclimate situations for roll films including several alternative enclosure choices, the use of additional materials inside sealed containers (i.e., molecular sieves, silica gel, buffered cardboard) and moisture preconditioning prior to sealing the film in a microenvironment. This article presents the experimental procedure, results, and the implications for current strategies in acetate film preservation.

Experimental

The experimental approach was aimed at determining effectiveness of various storage configurations in minimizing further degradation of pre-incubated (and partially degraded) CTA film base. Film in roll form was used to reflect as closely as possible real-life storage situations. Because moderate temperatures were used (40°C, 35°C and 21°C), the film was brought to the onset of vinegar syndrome prior to the experimentation. This approach had two advantages: (1) significant acidity changes could be observed in less than 2 years even at those moderate temperatures and (2) the initial free acidity in the base presented a situation where we could evaluate the effectiveness of acid-scavengers.

Film Sample. Fujicolor Positive Film (Type 8816) on CTA base was used for this study. After standard Eastman Color Print (ECP-2) processing, the film was first pre-degraded to bring the material to the onset of vinegar syndrome. This was achieved by incubating 1000-ft rolls in

heat-sealed aluminum foil bags for a pre-determined period at 90°C 50% RH. Subsequently, 100-ft rolls of this pre-degraded film were prepared as sample units for subsequent studies.

Enclosures. The impact of various enclosures was studied by placing 100-ft pre-degraded film rolls in one of the five following containers: buffered cardboard box, untaped metal can, metal can without lid, untaped plastic microfilm box, and a drilled plastic microfilm box.

Microenvironments. These were obtained by the use of sealed metal cans. Three basic approaches were tested: (1) moisture control by use of a desiccant or by moisture pre-conditioning, (2) acid removal by the addition of an acid-scavenger, and (3) acid neutralization by the introduction of cardboard containing calcium carbonate buffering. These three mechanisms may be additive in some situations.

Silica gel grade 43 (14 to 20 mesh) with color indicator was used for its moisture adsorption property. Prior to use, individual packets of silica gel were reactivated in a dry oven at 110°C for 24 h. Molecular sieves (zeolites) provided by Eastman Kodak Co. have the property to adsorb both moisture and acetic acid vapors. This feature of a carefully chosen type of zeolites[22] has been reported to minimize further deterioration of acetate film base catalyzed by the acidic by-products. Cardboard disks containing 5% by weight of calcium carbonate (and some also containing zeolites) were included to evaluate the contribution of a common buffer in neutralizing the generated acid vapors. This aspect was also explored in a parallel study on acetate-base sheet films.[4]

Measurements. The chemical decay of the film was determined by measurement of film acidity. Early studies showed that free acidity is the most sensitive indicator of acetate degradation.[10] A method based on water-leaching was used exclusively during this study.[26] Duplicate determinations were made on three locations along the length of the 100-ft roll (10, 50, 90 ft). Separate film rolls were used for each pull time. When appropriate, analysis was augmented by monitoring the moisture content (for film and desiccant) using a gravimetric approach.

Results

Acid Diffusion Rate. Fundamental to the control of vinegar syndrome by means of catalyst removal is the rate of acid diffusion from the degrading film to the surrounding environment. In an earlier study, cellulose acetate butyrate sheet films were incubated at 50°C 50% RH in contact with interleaving nonbuffered paper. After 1 year, it was found that less than 20% of the acid generated in the base had migrated into the adjacent paper receptor.[4] These data suggested a slow acid diffusion rate compared to the degradation rate, even when the contact area between the sheet film and paper receptor was optimized and the temperature was elevated.

Film rolls have a less advantageous situation compared to sheet film. The exposed area of the film is physically limited by the shape of the roll. Figure 1 illustrates the impact of film configuration on the acidity loss when degraded CTA film was exposed at 21°C 50% RH. The film was pre-degraded to an acidity level of 0.4 (mL NaOH 0.1 M/gram of film) prior to exposure in two distinct formats—i.e., in strips and in a 100-ft roll. The acid diffusion rate was significantly slower for the film roll compared to the strips. After 3 months at 21°C 50% RH, the acidity level remained the same in the roll, whereas a significant de-

TABLE I. Free Acidity Level (in mL NaOH 0.1 M/g of Film) of CTA Film Rolls Stored in Various Containers at 21°C 50% RH; Acidity Values Were Determined In Duplicate on Three Locations in the Roll (10, 50, 90 ft)

Enclosure and initial acidity range	3 months	6 months	10 months	15 months	20 months	24 months
Taped Metal can 0.55–0.65	0.59	0.66	0.71	0.82	0.63	0.67
	0.62	0.67	0.69	0.80	0.64	0.63
	0.58	0.67	0.72	0.88	0.66	0.67
Metal can w/o a lid 0.35–0.50	0.36	0.37	0.40	0.46	0.47	0.54
	0.40	0.42	0.43	0.48	0.50	0.44
	0.40	0.41	0.44	0.45	0.51	0.41
Cardboard box 0.35–0.45	0.43	0.37	0.39	0.42	0.33	0.46
	0.48	0.48	0.40	0.51	0.46	0.33
	0.48	0.48	0.41	0.46	0.48	0.49
Taped Plastic box 0.40–0.60	0.60	0.52	0.54	0.61	0.67	0.77
	0.55	0.49	0.55	0.60	0.69	0.64
	0.57	0.48	0.54	0.62	0.67	0.75
Roll in drilled plastic box 0.55–0.65	0.55	0.65	0.68	0.77	0.53	0.98
	0.56	0.65	0.70	0.77	0.83	0.76
	0.54	0.66	0.71	0.76	0.70	0.90
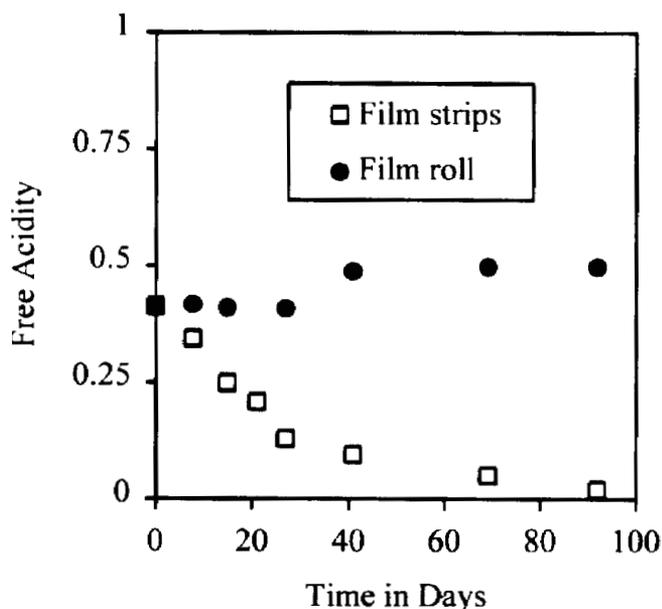
Figure 1. Acidity of degraded CTA film when exposed at 21°C 50% RH in two film formats (i.e., strips and roll).

Figure 2. Effect of enclosure designs on the acidity of degraded CTA film rolls determined after 8 months incubation at 40°C 50% RH.

crease was observed for the strips. These data prompted two conclusions:

1. Diffusion of acid from the film must occur first to realize benefit from vented enclosure designs or acid adsorption effects provided by any housing system.
2. Because the acid diffusion from a roll is so slow, the effectiveness of ventilation or acid adsorption depends on the rates of both acid generation and acid diffusion. It is important that the experimental conditions produce the same relative rates between these two processes as found under practical conditions. For this reason, the possibility exists that high-temperature incubation may lead to suspect conclusions. Consequently, the incubation temperature should be as low as possible and therefore, temperatures between 21°C and 40°C were chosen in this study.

Effect of Enclosure Design. This part of the study compared the behavior of different enclosure materials (tin-plated iron, polypropylene, buffered cardboard) and design. Figure 2 illustrates the acidity of 100-ft film rolls kept in various enclosures after 8 months at 40°C 50%

RH. A significant acidity increase over the initial acidity level (0.1 to 0.2) was observed for the tightest sealed enclosure (i.e., untaped plastic box), whereas the buffered cardboard box displayed the lowest acidity level. This can be attributed to the porosity of the cardboard, allowing acid escape. In this case, as for the can without a lid, it seems that the "ventilation effect" reduces the acidity levels at 40°C. It also seems that tighter enclosures lead to higher acidity levels. These observations are consistent with previous analysis;[17] however, further monitoring is still in progress. It is not known if the "ventilation effect" improvement is significant at room temperature because a higher temperature (40°C) promotes greater acid diffusion from the film than would exist under normal conditions.

At 21°C, similar experimental configurations (taped metal can and plastic box) did not display significant differences after 2 years of monitoring (see Table I). This data showed that open enclosures did not have a significant impact in lowering the acidity of the pre-degraded film. This study at 21°C is continuing.

Effect of Cardboard Addition to Microenvironments. Pre-degraded 100-ft film rolls were first conditioned to 21°C 50% RH prior to incubation at 40°C in sealed metal cans with (1) cardboard containing 5 wt % calcium carbonate, (2) cardboard containing calcium carbonate and zeolites, and (3) molecular sieves. Figure 3 illustrates the benefit obtained using 5 wt % molecular
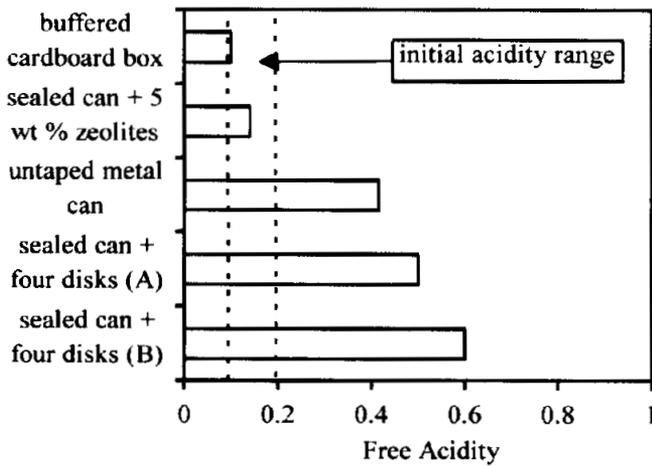
Figure 3. Effect of cardboard disks in sealed cans on the acidity of degraded CTA film rolls after 8 months incubation at 40°C 50% RH. Disks (A): cardboard with $CaCo_3$ and zeolites. Disks (B): cardboard with 5 wt% $CaCo_3$.

Figure 4. Acidity of 100-ft CTA film rolls incubated at 35°C in various microenvironmental alternatives.

Figure 5. Moisture equilibrium curve for 35-mm motion-picture film on CTA base and determination of equilibrium RH obtained by use of molecular sieves and activated silica gel.

sieves, whereas both types of cardboard caused a significant increase of film acidity. This behavior is explained by the fact that molecular sieves adsorbed moisture, but the cardboard disks introduced extra moisture into the sealed can. The latter detrimental effect has been documented in an earlier study.[4] It is interesting that the same buffered cardboard (5% $CaCO_3$) used either as an enclosure material or as additional disks inside the sealed film container led to opposite behaviors. When buffered cardboard was used as enclosure material the "ventilation effect" dominated and when used as additional disks inside the sealed container the result was increased moisture.

The benefit obtained with 5 wt % molecular sieves encouraged further study on this microenvironment option.

Effect of Molecular Sieves, Silica Gel, and Moisture Pre-Conditioning. Seven different microenvironments were subsequently investigated. They correspond to three alternative approaches: (1) moisture control and acid adsorption by using molecular sieves, (2) moisture control by the addition of activated silica gel, and (3) moisture control by moisture pre-conditioning at low RH.

The 100-ft film rolls were first conditioned to 21°C 50% RH prior to being sealed in metal cans. For each adsorbent, two percentages were tested (i.e, 2.5 and 5 wt % of molecular sieves; 1.8 and 3.6 wt % of silica gel). Film rolls were also pre-conditioned to 50, 35, and 20% RH at 21°C prior to being enclosed in sealed cans without additional materials. Separate film rolls were used for each pull time and incubation extended for 18 months at 35°C. The degradation rate was determined by monitoring the acidity of every roll at three locations for each pull time as previously described.

Figure 4 illustrates the effect of the various microenvironments on the stability of degrading CTA film base. By comparing the acidity changes to the control curve (i.e., film conditioned to 21°C 50% RH incubated without adsorbent), one can evaluate the relative benefit of each configuration. Film conditioned to a lower RH than 50% or stored in the presence of silica gel and molecular sieves displayed an improved stability to various degrees.

Increasing the percentage of molecular sieves (from 2.5 to 5 wt %) had a marked impact. The same behavior was observed with silica gel. Also of interest is that two basically distinct options (i.e., pre-conditioning to 21°C 20% RH and addition of 5 wt % of molecular sieves) led to a
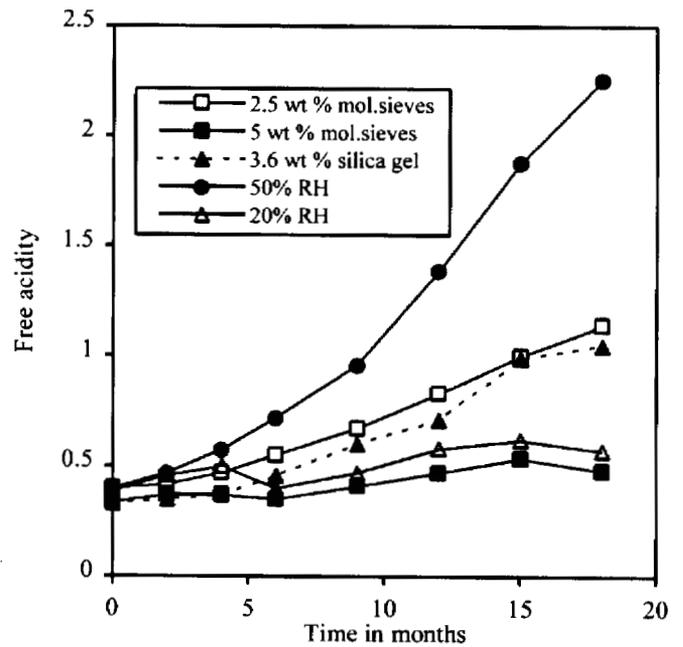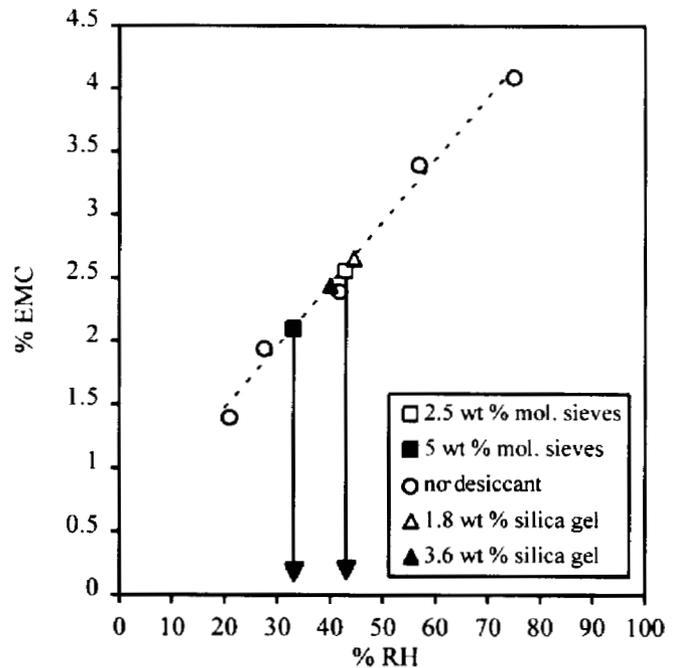
similar stability improvement. Neither configuration displayed any significant acidity increase. However, the beneficial mechanisms involved are different. The moisture pre-conditioning procedure reduced only the percent moisture content of the film. Molecular sieves altered the microenvironment by adsorbing both moisture and acid vapors.

Mechanisms Involved in Microenvironments. To understand the relative importance of moisture level and acid adsorption on reducing the acidity level, the percent equilibrium moisture content (%EMC) of the photographic film was determined gravimetrically. A 100-ft film
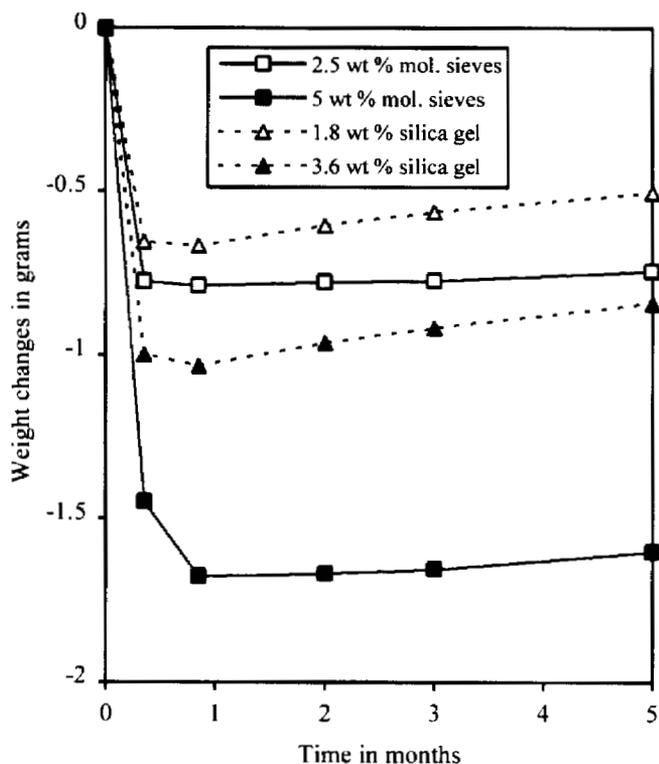
Figure 6. Weight change for a 100-ft 35-mm motion-picture film roll on CTA base initially conditioned to 21°C 50% RH then enclosed in sealed cans with desiccants.

roll was conditioned successively to different relative humidities at 21°C, and the weight increase over film that was oven dried was plotted as a function of relative humidity. The resulting moisture equilibrium curve (see Fig. 5) was then used to determine the equivalent equilibrium RH of each experiment discussed in the previous section. This was accomplished by measuring the weight of moisture extracted from film rolls at 21°C 50% RH that had been conditioned inside sealed cans with the same levels of each desiccant. Figure 6 reports the weight loss for rolls conditioned with these desiccants for a 5-month period. Moisture equilibrium was reached in less than 1 month and the magnitude of the weight loss depended on both the nature and percentages of the desiccant. Based on these weight losses (in Fig. 6), the weight percent moisture was calculated. These values were then translated into an estimated equilibrium RH for each desiccant experiment using the moisture equilibrium curve of Fig. 5. For example, 2.5 and 5 wt % of molecular sieves resulted in, respectively, 40 to 45% and 30 to 35% equilibrium RH for the film. The equilibrium RH estimation was confirmed experimentally by using a temperature/relative humidity sensor inserted into the film can.

Based on the above approach, the acidity levels reached after several incubation times were plotted against the equilibrium RH of the film. Figures 7 and 8 illustrate the results after 12 and 18 months incubation at 35°C. The line identified as "without additional material" shows the beneficial effect of only lowering the humidity (the data obtained from Fig. 4). The impact of acid adsorption is determined by comparing the acidity level obtained by the bars representing the different weight percent desiccant to the acidity obtained without additional material.

Based on Figs. 7 and 8, the advantages of molecular sieves and activated silica gel appear to result from both
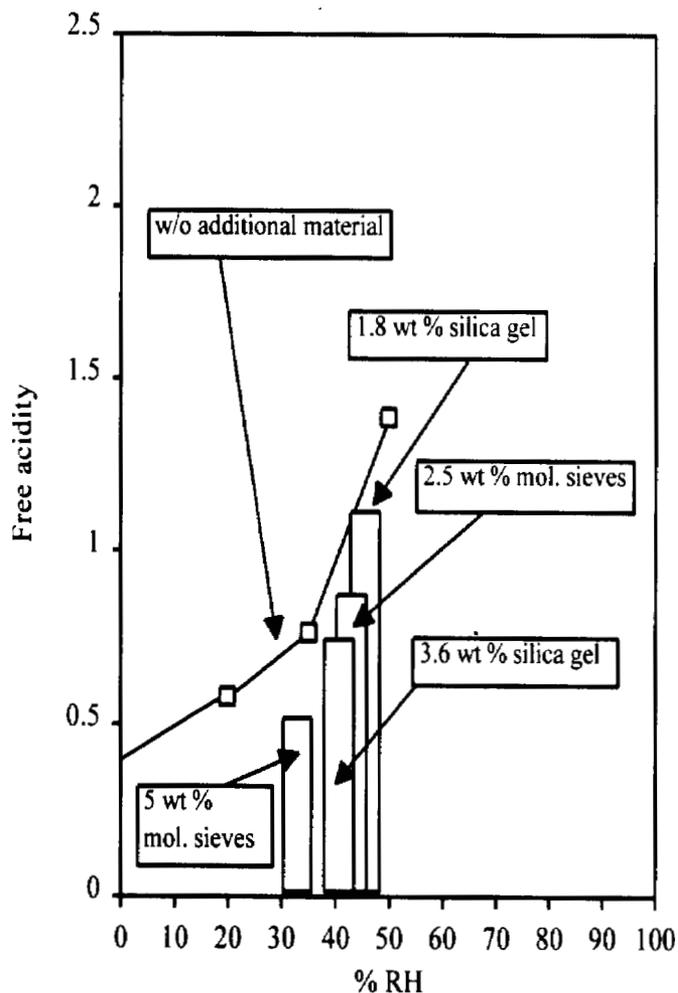
Figure 7. Acidity of CTA film rolls after 12-month incubation at 35°C in sealed cans with various desiccants.

moisture and acid adsorption. However, recognize that this experiment was made at 35°C, which is considerably higher than room conditions. For this reason, the same experimental approach was repeated at 21°C. This temperature reflects practical conditions. However, this has the disadvantage that the acidity changes are small over the same period of time.

The separate film rolls used for each pull time had been pre-incubated to an acidity level of approximately 0.4. However, because the initial acidity levels were not absolutely identical and the changes observed were small, all acidity values were corrected for the initial level determined on the same film roll prior to incubation. The acidity increase over the initial stages of degradation is sufficiently linear with time to justify this correction. Consequently, the data reported in Table II are acidity changes that cover a 20-month period of storage at 21°C. The film rolls pre-conditioned to 35 and 50% RH then sealed without additional material showed a consistent acidity increase. A similar trend was observed for the film stored with 1.8 wt % of silica gel although the differences were rather small. Film rolls pre-conditioned to 21°C 20% RH and stored with 3.6 wt % silica gel or 2.5 and 5 wt % molecular sieves remained at their initial acidity level. By comparison to the 50% RH control, the merit of molecular sieves and moisture pre-conditioning to 20% RH may be significant in postponing further degradation of the film. In other words, these levels of silica gel and molecular

TABLE II. Free Acidity Change (in mL NaOH 0.1 M/g of Film) of CTA Film Rolls Stored in Sealed Cans at 21°C in Various Microenvironments; Acidity Values Were Determined in Duplicate on Three Locations in the Roll (10, 50, 90 ft)

Microenvironmental alternatives	3 months	6 months	10 months	15 months	20 months
2.5 wt % molecular sieves	+ 0.02	0	0	+ 0.05	+ 0.09
	+ 0.02	+ 0.05	+ 0.05	+ 0.06	—
	+ 0.01	+ 0.02	+ 0.01	− 0.04	+ 0.10
5 wt % molecular sieves	0	+ 0.02	+ 0.03	+ 0.02	+ 0.01
	− 0.01	+ 0.02	− 0.02	+ 0.01	—
	+ 0.02	+ 0.02	+ 0.02	+ 0.02	+ 0.03
1.8 wt % silica gel	+ 0.01	+ 0.05	+ 0.04	+ 0.07	+ 0.12
	+ 0.01	+ 0.05	+ 0.06	+ 0.07	—
	+ 0.02	+ 0.04	+ 0.04	+ 0.12	+ 0.15
3.6 wt % silica gel	− 0.01	− 0.04	+ 0.02	+ 0.12	+ 0.03
	− 0.02	− 0.01	+ 0.02	+ 0.02	—
	+ 0.01	− 0.04	0	+ 0.04	+ 0.03
Pre-conditioning to 21°C 50% RH	+ 0.03	+ 0.06	+ 0.13	+ 0.16	+ 0.29
	+ 0.03	+ 0.07	+ 0.12	+ 0.15	—
	+ 0.04	+ 0.07	+ 0.10	+ 0.15	+ 0.37
Pre-conditioning to 21°C 35% RH	+ 0.04	+ 0.03	+ 0.07	+ 0.17	+ 0.16
	+ 0.07	+ 0.04	+ 0.08	+ 0.08	—
	+ 0.05	+ 0.03	+ 0.11	+ 0.14	+ 0.16
Preconditioning to 21°C 20% RH	0	− 0.01	+ 0.01	+ 0.03	+ 0.02
	+ 0.01	+ 0.01	+ 0.01	+ 0.05	—
	+ 0.07	− 0.01	+ 0.01	+ 0.02	+ 0.03
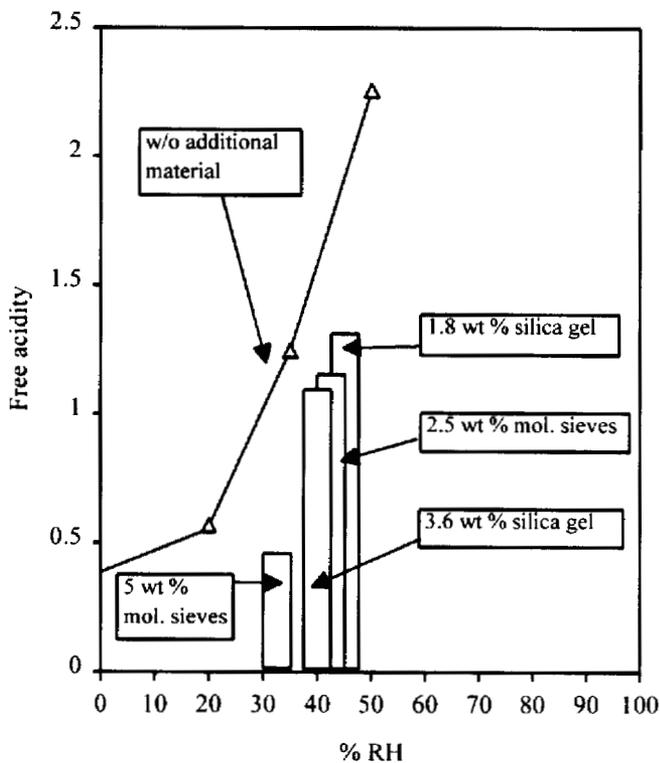
Figure 8. Acidity of CTA film rolls after 18-month incubation at 35°C in sealed cans with various desiccants.

Figure 9. Acidity of degraded CTA film on reel enclosed in a sealed container without and with 10 wt % molecular sieves at 21°C.

sieves appear effective in retarding further degradation, comparable to moisture conditioning at 20% RH. However, these data also indicated that acid-scavengers did not have a significant impact in lowering the acidity of the pre-incubated and slightly degraded CTA film. This latter observation casts some doubt regarding the effectiveness of molecular sieves for curative purposes. The experiment at 21°C is continuing.

Curative Applications for Acid Adsorbers. While the previous experiment indicated that acid adsorbers offer advantages in retarding further base degradation, they do not lower the acidity of already degraded film to an acceptable level. To further evaluate possible curative applications, a very seriously degraded film with an acidity level of 1.6 was exposed in a sealed container in the presence of molecular sieves. In this experiment, the diffusion rate was optimized by placing the film on a processing reel that allowed total exposure of both sides. Although this configuration did not reflect the reality of a film roll, it served the purpose of this experiment. Figure 9 reports the acidity change of 10 g of pre-degraded film. The addition of 10 wt
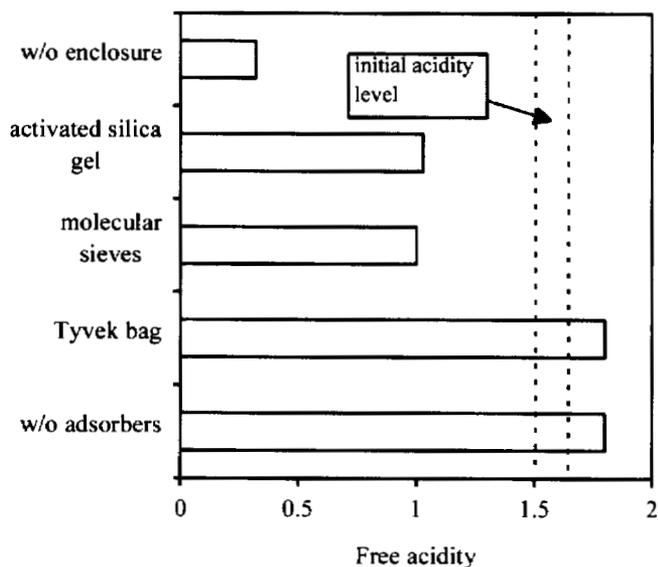
Figure 10. Acidity of 10 g of degraded CTA film exposed on reel for 2.5 months at 21°C with 12.5 g of molecular sieves and 12.5 g of activated silica gel inside sealed cans.

% molecular sieves produced only a small decrease in acidity even after 1 year.

The same experimental approach was repeated using a much higher percentage of molecular sieves and activated silica gel, namely, 12.5 g of adsorbent and 10 g of degraded film inside a sealed can. In addition, the "ventilation effect" offered by the film without an enclosure and the impact of a Tyvek® packet was also tested. The results are reported in Fig. 10 and showed a similar acidity loss when the film was either in the presence of molecular sieves or activated silica gel. This confirmed that silica gel may also play a role as acid-scavenger as indicated by Figs. 7 and 8. The greater acidity decrease obtained when the film was stored without a film can was not surprising because a very high surface area was exposed and the film acidity level was very elevated. Under these exaggerated conditions, the molecular sieves and silica gel displayed some acid-trapping capacity, but the acid levels remained relatively high. This suggests that the use of acid-scavengers even in large amounts cannot reduce the acidity of degraded CTA film to acceptable levels.

These studies are all consistent and indicate that acid adsorption does not offer a practical method of reducing the acidity of degraded CTA film.

Implications to Current Strategies

Enclosures. The information gained during this study documented the detrimental effect of tight enclosures. However, an improvement using "vented" enclosures was not observed at 21°C even after 2 years. This suggests that film enclosure design has only a secondary role compared to the marked effect of temperature and relative humidity in controlling the stability of CTA film base.[18]

Microenvironments. Aside from considerations of equipment cost and power expenses for use of macroenvironments and labor costs associated with microenvironments, the archivist must consider the benefit associated with each alternative. The option of using microenvironments featuring molecular sieves, silica gel, or moisture pre-conditioning at low RH should be compared to the benefit of the macroenvironmental approach. Based on the information obtained at 35°C reported in Fig. 4, the effect

of 2.5 wt % molecular sieves can be estimated. By choosing an acidity end point of 1, the addition of 2.5 wt % molecular sieves improved the base stability by approximately a factor of 2 (i.e., from 10 to 20 months). Based on Arrhenius predictions, only a 5°C decrease at 50% RH should have a similar effect.[18] In the future, additional data may provide a better quantitative assessment of the respective benefit in terms of life expectancy. However, the benefit of low-temperature macroenvironment storage far exceeds that of microenvironmental storage at room temperature. However, microenvironments are viable options for controlling the moisture content of film in sealed cans as a substitute for dehumidification equipment.

Conclusions

1. At 40°C, the detrimental effect of vapor-tight enclosures on the stability of cellulose triacetate base film was documented. After 2 years at 21°C, however, the merit of open enclosures in lowering the acidity of degraded CTA film was not demonstrated.
2. The use of buffered cardboard disks in sealed film cans is not recommended based on detrimental effect at 40°C.
3. Microenvironments creating a lower film moisture content benefit the stability of cellulose triacetate base film. This can be obtained by pre-conditioning the film to 21°C 20% RH or by the addition of molecular sieves or silica gel.
4. The acid-adsorption property of 5 wt % molecular sieves made a significant contribution in minimizing further degradation of cellulose triacetate base film at 35°C. This preventive benefit was also observed after 20-month storage at room temperature, comparable to that obtained by lowering the equilibrium RH to 20%.
5. Molecular sieves had minimal impact on reducing the acid content of cellulose triacetate base film that had already started to degrade. In such situations, cold storage is recommended until the film can be duplicated.
6. The use of microenvironments is highly recommended when it is not possible to control the macroenvironment. However, the benefits obtained by microenvironments do not equal those obtained by temperature and humidity control of the storage area. ▲

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