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SUMMARY REPORT OF RESEARCH AT THE NATIONAL BUREAU OF STANDARDS ON THE STABILITY AND PRESERVATION OF RECORDS ON PHOTOGRAPHIC FILM

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SUMMARY REPORT OF RESEARCH AT THE NATIONAL BUREAU OF STANDARDS ON THE STABILITY AND PRESERVATION OF RECORDS ON PHOTOGRAPHIC FILM

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ABSTRACT

As photographic film has become an important documentary material, a systematic study of it was undertaken by the National Bureau of Standards as a part of its general research on problems relating to the preservation of records. This summary was prepared in order to have the more important information developed available in one publication.

The films tested are of two types, one coated with a photographic emulsion and the other having a light-sensitive dye incorporated in the base for forming the image. The sheetings comprising the bases are, for the first type, nitrate and acetate, and for the second, viscose and acetate.

The stability of the films was determined by heating them at 100° C for various periods and testing them for decrease in folding endurance, weight, and viscosity of solutions, and for increase in acidity. The acetate and viscose bases were also tested for increase in copper number under the heat test. Both types of acetate film tested were very stable and are considered suitable for permanent records. The nitrate film is of little value for record purposes because of its inflammability and instability. The viscose film was in an intermediate position and appears to be suitable for records requiring moderate longevity. The images of the acetate and viscose films were not affected appreciably by the heat treatment. The emulsion type of film was also tested for presence of sodium thiosulfate, and that having an acetate base was in addition tested for presence of nitrate. To aid in the selection of acetate film for permanent records, values are given for the strength, stability, and chemical purity considered desirable.

Apparently the combined effect of the light and temperature to which film is exposed in projectors designed for documentary use is not a serious consideration. Relative to possible fading of photographic images when exposed to light, those contained in emulsion are known to be very stable if properly made, and exposures of both the acetate and viscose Ozaphane film indicated that images in such film are likewise very resistant to fading if the proper dyes are used.

As acetate film becomes brittle when dry, it is recommended that it be stored at a relative humidity of about 50 percent. The special precautions required for storage of nitrate film because of its inflammability are described. The results of investigation of the size of the pressure-relief vents necessary to prevent, in case of fire, explosion of vaults containing nitrate film indicate that vents larger than those previously recommended may be desirable.

Micromethods for finding the chemical condition of record-bearing films without affecting their serviceability were developed.

To minimize the damage to film records through scratching and handling, it is recommended that they be cleaned with carbon tetrachloride and handled with clean white cotton gloves.

A list of the more detailed published reports of this work, together with those dealing with paper as a record material is given.

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I. INTRODUCTION

Active research on problems relating to the preservation of records has been in progress in the paper section of the National Bureau of Standards since 1929. This work has dealt with the properties of papers and photographic films with particular reference to their stability and strength, and with means of minimizing extraneous deteriorative influences during the storage and use of these materials.

The work has been conducted with the assistance of an advisory committee appointed by the National Research Council, and representative of library, archival, and manufacturing interests. In addition to funds of the National Government, the Bureau has received the financial assistance of the Carnegie Foundation of New York, and of manufacturers of the materials. Research on the use of photographic films was undertaken in 1935. For this work, in addition to funds from the Carnegie Foundation, the Bureau's funds have been supplemented by those of three other Government organizations—The National Archives, the Department of Agriculture, and the Social Security Board—and by a fund deposited with the National Research Council by several manufacturers of photographic films and equipment. Also, helpful advisory assistance was given by a committee representative of these interests.

The research related to the preservation of records contained on paper resulted in a recommended classification and specification of papers for the various classes of records, in information which assist the papermaker in choosing his raw materials and making the best use of them in manufacturing record papers, and in recommended storage conditions for their preservation. The results of this work are summarized in a report (Miscellaneous Publication M154) similar to this one.

When photographic films became of importance as a record material there was little definite information on their stability, resistance to wear, or optimum conditions of storage. Systematic investigation on these problems was, therefore, undertaken by the Bureau as a natural extension of its general studies made to assist in the preservation of records. The results so far obtained are herein summarized and for further details the reader is referred to the reports listed in the appended bibliography. Much of the material contained in this report has already been published in the Proceedings of the Fourteenth International Conference of the International Federation for Documenta-

tion under the title "Summary Report of Research at the National Bureau of Standards on Materials for the Reproduction of Records."

II. VALUE OF FILM AS RECORD MATERIAL

During the past decade, photographic films of the motion-picture type have assumed in the documentary field a position commensurate with that of paper. Of the many materials used for conveying information, such as stone, clay, metal, animal hide, and papyrus, paper first permitted the wide dissemination of knowledge at such low cost that printed matter ultimately became within the reach of everyone in the civilized countries and thus paper, together with printing, became a prime mover in the advance of civilization. But documentary material has now become so voluminous that it is necessary to condense it; much is contained on impermanent paper and, therefore, must be preserved by reproduction in permanent form; it is desirable to render records which cannot be removed from depositories more accessible by reproducing them for distribution; and it is desirable to reproduce records to minimize wear of the originals by handling. The photographic films fulfill the requirements admirably because of the simplicity of the process of reproduction and its low cost, and the great reduction in the size of the record.

Special cameras have been developed which automatically photograph on films successive images of pages of printed or written matter as fast as they can be passed before the lens. Various forms of reading devices have been devised, ranging from the small hand lens for direct reading to compact projectors which place the magnified image of the record before the reader in convenient form for reading at a desk, and which have means of turning film records in reel form to any desired image as readily as turning the pages of a book.

In the conservation of storage space for records, the films are preeminent. At the U. S. Census Bureau, where all of the census records are being duplicated on film, the data on cards requiring 7,000 square feet of storage space are now contained on film requiring only 50 square feet. At the New York Public Library, one year's bound issue of the New York Times occupies a storage space of 108 cubic feet; duplicated on film the space is decreased to ⅓ cubic foot. The cost of reproduction is very low, particularly for large-scale operations. Many of the leading libraries, and other organizations, furnish film copies of records on order at very small cost; as low as 1 cent or less per page for large orders.

It is for these reasons that films have become a widely used record material. Nearly all of the larger organizations of the National Government make extensive use of them, the use of them as a part of library service has been mentioned, and they are used extensively for the records of department stores, banks, insurance companies, and many other commercial activities which require the keeping of extensive records. Several of the leading newspaper publishers are having issues that are printed on the usual impermanent paper filmed for storage.

It should be remarked, however, that paper is still of much importance in the reproduction of records and may assume greater importance with further development of new types of papers and new kinds of processes. Copies of records in reduced size but legible without

magnification are often printed from film to paper, thus obviating the need of equipment for magnification, and this is done at small cost. Furthermore, miniature prints on paper have a potential field.

Many important records, of course, are taken directly on film in the form of motion pictures and sound recordings. In addition to extensive use of such records for educational purposes, they have the advantage historically of being "live" records; they present a truer picture of personages and happenings than can be obtained from words or still photographs. One of the most important forms of records of this kind are the news reels shown in theaters. Unfortunately, these are on an unstable type of film and, as in the case of newspapers printed on unstable paper, the more important ones should be transferred to stable film. Another extensive use of films is for aerial photography in such operations as mapping, crop, timber, and soil surveys, and observations in warfare.

For information on the whole subject of the reproduction of records the Journal of Documentary Reproduction should be consulted This is a quarterly review of the application of photography and allied techniques to library, museum, and archival service, issued by the American Library Association.[1]

III. TYPES AND KINDS OF FILMS

The films tested comprise two types, each made with two kinds of base. One type, the more common, consists of transparent "cellulose sheeting," usually about 0.0055 inch in thickness, coated with a photographic emulsion composed of a thin layer of gelatin containing a silver compound extremely sensitive to light. The other type, which has the trade designation Ozaphane, has instead of the emulsion a light-sensitive diazo dye incorporated in the cellulose sheeting for forming the image and is usually about 0.002 inch in thickness. The sheetings comprising the bases, designated according to the chemical process used in their manufacture, are, for the first type, nitrate and acetate, and for the second type, viscose and acetate.

Film having the cellulose nitrate base is the kind used in the theatrical motion-picture industry because it has certain advantages for this purpose. It is essentially a mixture of cellulose nitrate and camphor and is very inflammable. It ignites at low temperature, and burns rapidly with emission of inflammable and poisonous gas. Cellulose nitrate is unstable in any form and is capable of decomposition with little or no air supply. Like all film bases, it contains some form of plasticizer added to give increased flexibility. While, because of the inflammability and lack of stability of this kind of film, it is of no value for the reproduction of records, as has previously been mentioned, many valuable records are contained on it.

The acetate, or so-called "safety" film, consists of cellulose acetate. This is the kind used largely for other than theatrical purposes. Cellulose acetate is in itself very stable chemically, and film made from it presents no more fire or explosion hazard than paper.

The viscose sheetings, of which the wrapping material Cellophane is one form, generally have a moderate degree of stability and are also slow-burning like paper.

[1] 520 North Michigan Avenue, Chicago, Ill.

The dye type of film is of particular interest for record purposes as, because of its thinness and lack of the granular structure of photographic emulsion, better definition of the image may be secured, and the image is not so subject to damage by scratching as that contained in emulsion. The image on the film tested was black on a clear ground. The quality of the image in contrast and definition was fully equal to that of the emulsion type of film.

The samples of films tested consisted of those of the emulsion type of nitrate and of acetate base from three domestic manufacturers, and of the dye type, film of acetate base from a domestic manufacturer, and that of viscose base from both a domestic and a foreign manufacturer.

IV. EFFECTS OF ACCELERATED AGING

1. TESTING METHODS

In order to determine the stability of the films, it was necessary, of course, to use some form of accelerated aging. The Bureau has found that heating paper in dry air at 100° C (212° F) correlates satisfactorily with the natural aging of it, and that this procedure was the most suitable, in general, of several tried. In testing films, this method was likewise found to be superior to others investigated which consisted in heating the films in various ways in steam and in air of high humidity. Also, as in the testing of paper, the extent of deterioration on heating was measured primarily by finding the loss of folding endurance and the changes in significant chemical properties. In addition to testing for loss of folding endurance, all of the different films were tested for loss of weight, increase in acidity, and decrease in specific viscosity of solutions. The acetate and viscose bases were also tested for gain in copper number, and an additional kind of heat test was applied to the nitrate base. Tests were also made for residual sodium thiosulfate (hypo).

The folding endurance of the emulsion type of acetate and nitrate films was determined with a Pfund [2] tester, which is shown in figure 1. It consists essentially of a fixed jaw, *A*, and a movable jaw, *B*, which are opened and closed by the screws, *C*. In operation, a test specimen is clamped in place with the jaws at a maximum distance apart and folded by moving jaw *B* up against jaw *A*, then back against plate *D*. The folds are caused to form alternately on opposite sides of the jaws by directing the film with a blunt-pointed instrument. The testing length is controlled by the position of plate *D* which regulates the maximum distance between the jaws. The number of folds sustained by the film before breaking is recorded as the folding endurance. The instrument used tests specimens 15 mm wide, and the strips are cut approximately 50 mm long. The 15-mm width is taken from the center of the film by trimming off the edges. Although operated manually, this tester gave more uniform results than were obtained with the testers commonly used for paper. Difficulty was encountered in the use of the latter because slight distortion of the film on aging caused edge cracks when folded over the jaw edges. The Pfund instrument folds without tension, forming a small loop not in contact with

[2] This instrument was developed for the purpose by A. H. Pfund, Johns Hopkins University, for the DuPont Film Manufacturing Corporation.

any metal edge that might give a sheering effect, as is the case with the standard type of paper tester.

The dye type of film was too thin to be tested satisfactorily with the Pfund instrument. For such film, a tester used for paper, the Schopper, with a tension of 1 kg, gave very good results for film of viscose base. This tester was used according to the standard procedure for testing paper.[3]

The MIT folding endurance tester,[4] another type used for testing paper, was found preferable for the dye type of film having an acetate base. In this tester a tension of 500 g was used.

The emulsion type of films was tested at 65-percent relative humidity and 70° *F*, the standard conditions used for paper. The Ozaphane films stretched too much at this humidity so they were tested at 50-percent relative humidity. The absolute values obtained with the different kinds of testers and under the different humidity conditions are not comparable, but the changes in folding endurance expressed as a percentage of the original are comparable.

Increase in acidity of cellulosic materials on aging is one evidence that chemical decomposition has taken place, and the amount of increase is an indication of the extent of the decomposition. Measurements of acidity were made in terms of pH. One g of film was dissolved in 100 ml of acetone containing 10 percent, by volume, of water, and the pH of the solution was determined with a glass electrode.[5]

The amount of copper reduced from an alkaline solution of copper sulfate by a cellulosic material is a measure of the amount of degraded and, therefore, unstable cellulose present. The usual method for paper [6] was employed except that the acetate film was prepared for the test by dissolving it in acetone, precipitating the cellulose ester in hot water, and washing and dying it. In testing the dye type of films, unsensitized films were used to avoid any reducing effect of the dye. The test is not applicable to nitrate film.

The decrease in the viscosity of solutions of cellulose films is one of the most reliable measures of their chemical breakdown. According to Staudinger [7] the specific viscosity of long-chain molecules is directly proportional to the molecular weight, for dilute solutions of equal concentration. Molecular breakdown should, therefore, be accompanied by a proportional decrease in specific viscosity. The viscosities of the acetate and nitrate bases were determined as follows: One g of the film was dissolved in acetone in a flask and after the photographic emulsion had settled, the flask was immersed in a bath maintained at $30 \pm 0.02°$ C until temperature equilibrium was reached, the solution diluted to 100 ml with acetone, and 5 ml then transferred to an Ostwald pipette, also immersed in the bath. The time of flow of the solution was then measured and the viscosity calculated as ratio of time of flow of the solution to that of the solvent. As the viscose base is not soluble in acetone, the procedure used for it was that recommended by The British Fabrics Research Committee [8] and described by Clibbens and Little,[9] except that the concentration of

[3] TAPPI Standard T423m. Technical Association of the Pulp and Paper Industry, 122 East 42nd Street New York City, N. Y.
[4] Carson, Paper Trade J. **96**, No. 22 (June 1, 1933).
[5] T. K. Brownson and F. McCray, J. Chem. Soc. **127**, 2923 (1925).
[6] TAPPI Standard T430m.
[7] H. Staudinger, Die Hochmolecularen Organischen Verbindungen (Berlin, 1932).
[8] The Viscosity of Cellulose Solutions, Fabrics Research Comm., Dept. Sci. Ind. Research (London, 1932).
[9] J. Textile Inst. **27**, 285T (1936).

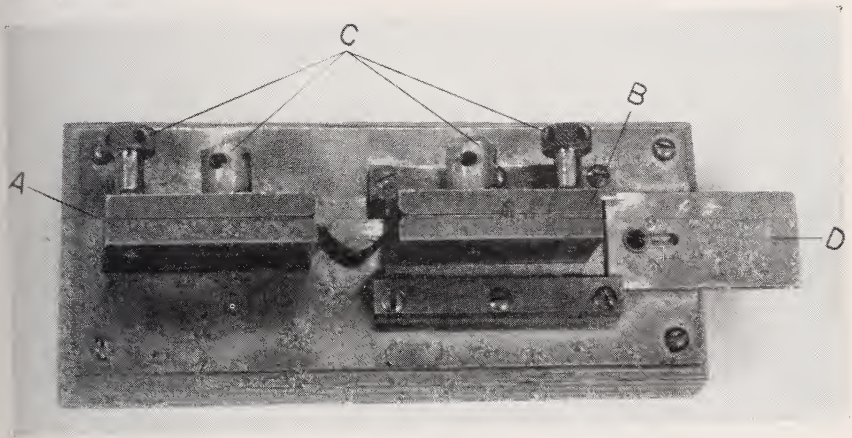

FIGURE 1.—*Pfund type of folding endurance tester used for determining the flexibility of motion-picture films.*

ammonia in the standard cuprammonium solvent was 240 g per liter as recommended by Clibbens and Geake.[10] The measurements were made at $21 \pm 0.05°$ C, using solutions containing 2 g of dry film per 100 ml of solution.

Sodium thiosulfate remaining after processing the photographic emulsion is deteriorative if present in too great an amount. This sometimes happens through insufficient washing of the emulsion. The test method used for detecting its presence is that of Crabtree and Ross.[11] The test consists in placing a strip of film in a solution of mercuric chloride in a test tube or glass cylinder and observing any turbidity which develops in the solution. If sodium thiosulfate is present in appreciable amount it reduces mercuric ion, and an insoluble mercurous compound is formed which causes the turbidity. If only a trace of thiosulfate or other reducing agent is present, the solution remains clear although the silver image is bleached white. The test solution contains 25 g of mercuric chloride, 25 g of potassium bromide, and water to make 1 liter. A 1.5-inch length of 35-mm motion-picture film cut into small pieces and immersed in 10 ml of solution was found to be a satisfactory amount for this test. The solution and film are allowed to stand 15 minutes, with occasional stirring, in order to give sufficient time for complete reaction.

Cellulose nitrate is commonly used in the substratum for the emulsion of acetate film to bind the emulsion firmly to the base, and it sometimes occurs in the base as an impurity. The development of a blue coloration when the film is tested with a solution consisting of 20 ml of concentrated sulfuric acid, 10 ml of glacial acetic acid, and 0.3 g of diphenylamine, indicates the presence of nitrate. This test is very sensitive, however, and a positive result obtained with it may not necessarily indicate the presence of enough nitrate to promote decomposition. The Bureau is making further study of the usefulness of this test.

The flash or explosion temperature is sometimes used to determine the condition of nitrate film, but it was found less satisfactory as a measure of stability than the method used by the Ordnance Department of the United States Army for testing guncotton.[12] In this test, a 1-g specimen is placed in a closed test tube with normal methyl violet paper inserted in the tube to about 2.5 cm above the test specimen. The time required at a constant temperature of 134.5° C for the gases given off from the specimen to change completely the color of the paper to salmon pink is observed.

The methods described are not applicable to films containing records because in obtaining the amount of film required for test some of the image or images would be destroyed. Tests of record-bearing film on receipt of it by a repository and tests to determine the condition of such film in storage are often desirable. For this reason, methods were developed which require only 0.007 g of film. This amount can be taken from the film with a small hand punch without injury to any image and without appreciably affecting the serviceability of the film otherwise. The micro methods developed were for acidity, viscosity, and residual hypo, and these are considered a sufficient index of the chemical condition of films. The essential

[10] J. Textile Inst. **19**, 77T (1928).
[11] J. Soc. Motion Picture Engrs. **14**, 419 (1930).
[12] U. S. Army Specification No. 50-14-3.

modifications of the methods described in the foregoing are as follows: In the determination of acidity, the specimen is placed in a test tube, 5 ml of acetone containing 10 percent of water by volume added, and the pH of the moisture measured with a micro pH-meter. For the viscosity test, the specimen is dissolved in a test tube with 5 ml of acetone, and the rate of flow of 3 ml of the solution found. In testing for presence of hypo, the specimen is placed on a glass slide, two drops of mercuric chloride solution added in such a way that the solution flows over the specimen and onto the glass, and the solution observed for turbidity. While the micro methods do not give sufficiently accurate results for use in the selection of films for record use, they do serve to indicate the approximate condition, and the necessity of making duplicate copies can be determined before the films are permanently damaged by visible deterioration.

2. RESULTS OF TESTS

When the films of the three different bases were heated at 100° C and reconditioned in the standard atmosphere all three kinds lost about 20 percent of their initial folding endurance in 3 days, but on prolonged heating, the folding endurance of the acetate decreased very slowly, while that of the nitrate continued to decrease very rapidly, and that of the viscose at an intermediate rate. At the end of 30 days of heating the retention of folding endurance for the acetate film was approximately 67 percent and that of the viscose was 13 percent, but the nitrate had no folding endurance, under the conditions of the test, after 10 to 15 days of heating. A part of the initial loss of flexibility is probably due to volatilization of residual solvents and plasticizing materials. The following changes all occurred on 30 days' heating at 100° C. All three bases showed loss of weight on heating, but it was only about 2 percent for the viscose and 3 percent for the acetate, while the nitrate lost nearly 10 percent. The acetate film showed practically no gain in acidity, the viscose gained slowly to a final 5.4 pH, which is a moderate figure, and the nitrate gained rapidly to a very acid condition, 2.3 pH. (The lower the pH value, the greater the acidity.) While the initial copper number of the acetate base was higher than that of the viscose, the values being, respectively, 3.2 and 1.0, that of the acetate increased only 10 percent as compared with 200 percent for the viscose. The values for retention of specific viscosity of solutions of the three bases also place them in the same order as do the other chemical tests and the folding endurance, the values at the end of the heating period being over 90 percent for the acetate, about 60 percent for the viscose, and about 6 percent for the nitrate. There is excellent correlation between the changes in viscosity and the decrease in folding endurance, and this indicates a sound basis for judging relative stability. The complete comparative data derived from the different tests are shown graphically in figures 2 to 6, inclusive.

The treatment at 100° C apparently had no adverse effect on the emulsion or on the images contained on acetate film. The emulsion on nitrate film progressively became softened and discolored with continued heating with final destruction of the images. The images of the dye-type of film were unaffected.

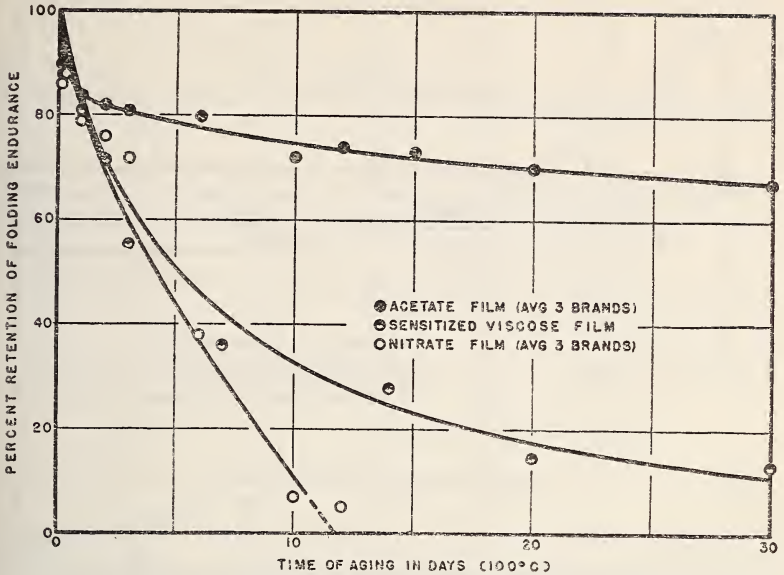

FIGURE 2.—*Effect of oven-aging on flexibility of films.*

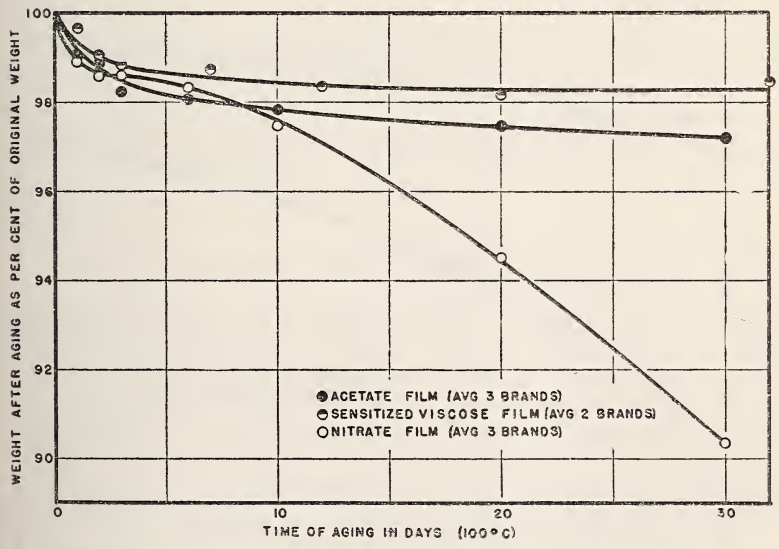

FIGURE 3.—*Loss in weight during oven-aging of films.*

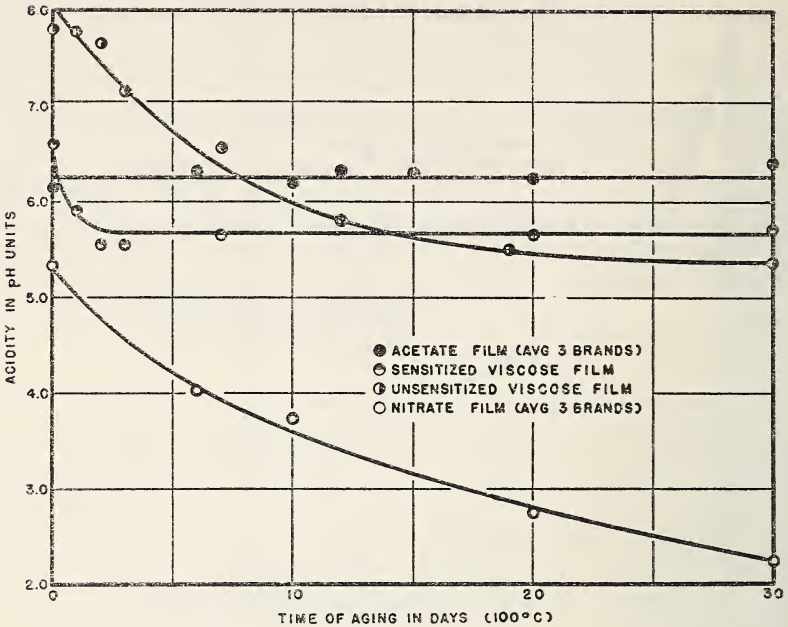

FIGURE 4.—*Effect of oven-aging on acidity of films.*

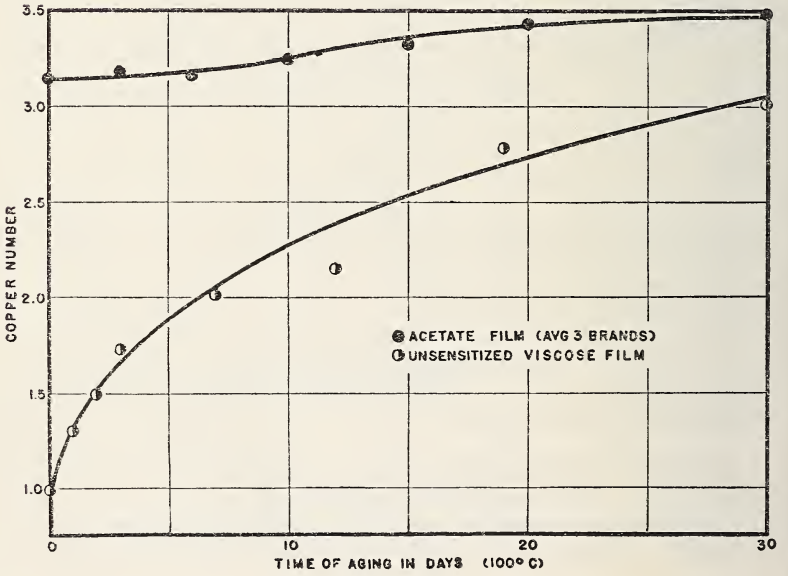

FIGURE 5.—*Change of copper number of films during oven-aging.*

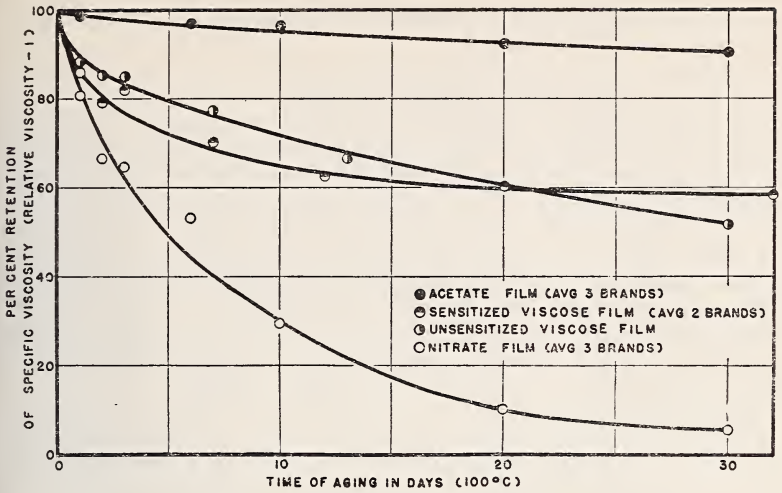

FIGURE 6.—*Effect of oven-aging on the viscosity of films.*

V. EFFECTS OF LIGHT

Tests have been made to find the effect of the light of the reading projector on films. By use of an illuminated oven, the conditions of one type of projector in extensive use were duplicated with respect to light intensity and temperature. On 24 hours' exposure, acetate film lost 17 percent of its folding endurance and viscose film last 74 percent. From a consideration of the small area of film exposed in the projector and the average length of exposure, the effect does not appear to be particularly serious, but further study of this is contemplated.

As far as resistance of photographic images to fading is concerned, it is well known that those contained in emulsion are very stable. On exposure of both the acetate and the viscose Ozaphane films to the action of carbon-arc light there was some reduction in the density of the image, but this did not appreciably affect the legibility of the document. The base turned clear pale yellow to about the same extent as usually occurs with a similar test of the emulsion type of acetate film.

VI. SELECTION OF FILMS FOR RECORDS

All of the foregoing test results denote that film of acetate base, whether of the emulsion or of the dye type, if of the quality tested, is as suitable for permanent records as the best grades of record papers.

From consideration of the data secured, it appears that for such use, the properties of suitable acetate film of the emulsion type may be defined as follows:

1. A Pfund folding endurance of not less than 16 double folds at 65-percent relative humidity and 70° F, with not less than 75-percent retention of folding endurance after heating 72 hours at 100° C.

2. A pH value of not less than 6, with a decrease of not more than 0.5 after heating 72 hours at 100° C.

3. An increase in copper number after heating 72 hours at 100° C of not more than 0.2.

4. A decrease in relative viscosity after heating 72 hours at 100° C of not more than 3.0 percent.

5. Developed film should not give a positive test for sodium thiosulfate when tested with mercuric chloride.

Film of this quality may cost more than the ordinary type used for motion pictures, as apparently special processing is necessary to produce film having the degree of chemical purity stated. Tests of film purchased for record use by the Government have shown in many cases that appreciable amounts of hypo and nitrate were present. Such film is probably suitable for use in reading rooms, where experience has indicated that film may become unserviceable with continued use through defacement of the image by scratching. Just what limits of hypo and nitrate content are acceptable for acetate film to be used for positive prints for reading rooms is not known but the Bureau hopes to obtain this information in further research.

The properties of the base of the dye type of acetate film suitable for permanent records are the same as those of the emulsion type, except that the original MIT folding endurance at 50-percent relative humidity is not less than 150 double folds at a tension of 500 g. With this type of film, while the presence of nitrate or hypo is not to be expected, there is the possibility of some developing agent being left in the film. If this should be the case the developing agent would in time oxidize and might discolor the film. Tests for this have not yet been worked out. In addition, in selecting this type of film, it is necessary to make certain that the dyes are sufficiently resistant both to fading by light and spontaneous decomposition. A satisfactory way of testing for light fastness is to expose developed film to carbon-arc light in a suitable type of apparatus, such as the Fade-Ometer, for a period of not less than 48 hours.

The data indicate that the Ozaphane type of film having a viscose base is definitely inferior in stability to good acetate film. It is not suitable for permanent records but apparently has sufficient stability for positive prints to be used in reading rooms. Its stability is comparable to that of ordinary sulfite wood fiber papers, which are known to last 25 years or longer under ordinary conditions if well made.

The situation with respect to choice of film for record purposes is analogous to that of record papers. As a result of its extensive studies of the properties and use requirements of writing and printing papers for record purposes, the Bureau recognizes the need for four classes of them, and has suggested detailed purchase specifications which comprise papers for records to be preserved (1) indefinitely (2) for 50 to 100 years, (3) for 25 to 50 years, and (4) about 5 years. It is felt that some such classification of films for record purposes is desirable and can be made after their use requirements become more definitely established and their properties better known. In respect of cost, paper suitable for permanent records costs about three times as much as the ordinary paper generally used for routine purposes because the former is a very special product. The same may hold for film because of the special processing required to produce a film of the high degree of stability required for records of perpetual value.

VII. PRESERVATION OF FILMS

1. STORAGE

Photographic films, in common with other cellulosic materials, are hygroscopic; their moisture content tends to follow that of the surrounding atmosphere. The acetate film, unfortunately, is particularly sensitive to moisture changes. When too dry it is brittle, it may give trouble from curling, and it exhibits relatively large dimensional changes with change in moisture content. Data obtained at the Bureau on the relationship between the folding endurance of films and the relative humidity to which they had been exposed, indicate extreme brittleness of acetate film at about 15-percent relative humidity and below. Such an atmospheric condition is not unusual in heated rooms without humidification. Films regain flexibility on humidification; therefore, if stored under a satisfactory degree of humidity, they should retain satisfactory flexibility. A condition of about 50-percent humidity, the same as recommended by the Bureau for paper, appears to be suitable. In libraries without conditioned air, storage in humidified cabinets is satisfactory. Cabinets and small rooms can be humidified by using open vessels containing a salt solution. A humidity of 52 percent at 68° F can be obtained by using a saturated solution of sodium dichromate. There should always be an excess of dichromate present to make certain that the solution remains saturated, and it should be exposed in a shallow vessel. If the space to be humidified is very large, the air should be circulated over the vessel with a fan.

The acetate films in roll form should be stored in open reels and on racks or perforated shelves or drawers so that the air has free access to all parts of the films. If the films have become very dry, as may occur through being stored in a dry atmosphere or after many successive projections have been made in a short period of time, it may be necessary to loosen the roll to humidify it as a dry, tightly wound roll will require weeks for moisture to penetrate through it. Nitrate and viscose film have better flexibility at low humidity than acetate film and, therefore, humidification is not so important for them. Film slides in card or strip form do not require control of moisture content if carefully handled when dry.

Relative to the dimensional changes which occur with change in moisture content, it does not often give serious trouble in projection apparatus as standard sprockets are made to allow for shrinkage and, furthermore, some projectors are made without sprockets. However, some difficulty may be experienced with curling.

Temperature is not an important factor in the storage of acetate and viscose films but extreme variations should be avoided as much as possible.

The high inflammability and lack of stability of nitrate film present, of course, special problems of storage and handling. Standards for the handling and storage of this type of film have been established by the U. S. National Board of Fire Underwriters.[13] It was considered desirable, however, to make further study of the areas of pressure-relief vents of vaults essential for safety; accordingly burning tests of

[13] Transactions of the National Board of Fire Underwriters (New York, N. Y.) Governing the Production, Storage, and Handling of Nitrocellulose Motion-Picture Film.

films were made in containers having adjustable vents and equipped with pressure gages. Four containers ranging in size from 197 cubic inches to 22 cubic feet were used. Approximately 100 burning tests were made, using various amounts of film and different vent areas for each container. A very satisfactory correlation was noted between the pressures developed and the amount of film per unit of vent area, and the relationship was constant regardless of the container or vault size. The pressure rises slowly with increase in the ratio of film to vent area until a critical point is reached above which the curve approaches the vertical. Beyond this point a slight increase in the ratio of film to vent will result in explosive pressures. From the data obtained, it would seem that the vent area required for safety is 20 square inches per 100 pounds of film, instead of the 14 square inches now used. However, the largest chamber used in these experiments had only a small fraction of the capacity of a standard-sized vault, and definite recommendations are being withheld pending the completion of full-scale experiments.

Nitrate film should be stored and transported in metal cans. Crabtree and Ives [14] designed cabinets with metal-lined, insulated compartments for the individual films to inhibit the spread of fire from one film to another. Such cabinets are now available commercially, and their use in safety vaults of suitable fireproof construction [15] [16] should afford adequate protection from fire. This system has been followed at The National Archives.[17] Low temperature and humidity retard the decomposition of cellulose nitrate but the advantage gained by storing at a temperature below about 50° F would probably be more than offset by the added costs of air conditioning, and the tempering difficulties involved in the prevention of condensation of moisture on films when they are removed to a warmer atmosphere for use.

Nitrate film should be inspected regularly for deterioration, and whenever found necessary the record should be reproduced on stable film. Heating nitrate film at 134.5° C, as described on page 7, serves as a satisfactory test for its condition. The effects of accelerated aging, as determined by this test, are shown in figure 7. The curves for the different commercial brands are alike in general characteristics, showing slow rates of change of stability for the first 2 days of heating, then sharp breaks in the curves, followed by much more rapid loss of stability. Old film visibly deteriorated by natural aging usually had a reaction time corresponding to 10 to 15 days of oven-aging at 100° C.

In large repositories, the precautions found desirable to minimize the damage to stored records contained on paper should be observed for films. An air-conditioning system should be used by means of which the temperature and the humidity of the air can be maintained uniformly, and positive circulation of air through the storage spaces effected. The air should be cleansed of acidic gases by washing it with an alkaline solution, and it should be filtered to remove dust. The use of nondusting materials of construction, such as tile or certain plastic products, and frequent dusting with vacuum appliances are helpful.

[14] J. Soc. Motion Picture Engrs. **15,** No. 3 (Sept. 1930).
[15] J. Soc. Motion Picture Engrs. **16,** No. 6 (June 1931).
[16] See footnote 13.
[17] J. Soc. Motion Picture Engrs. **26,** No. 6 (June 1936).

2. USE

The images of films, particularly those of the emulsion type of film, are subject to damage by scratching and handling. Scratching may occur from dust or may be caused by the projector. The oils and acids of the hands may cause damage. For these reasons, it is important that film be kept clean. Chemically pure carbon tetrachloride is a satisfactory cleaning fluid as it is a good solvent for fats and oils, evaporates readily, is noncombustible and does not have any measurable deteriorative effect. It should be applied with a soft cloth, such as silk plush. Film should always be handled with clean, white cotton gloves.

There are many preparations on the market made for the purpose of hardening the emulsion of films to make it more resistant to scratch-

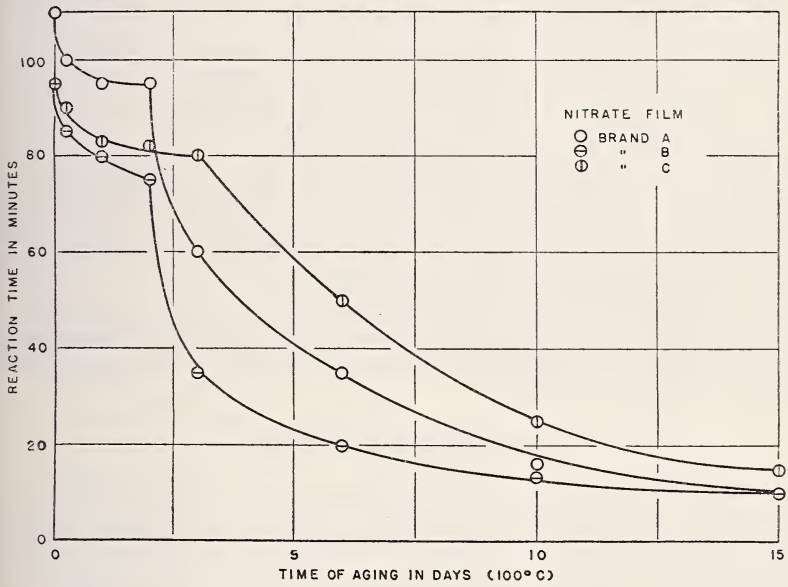

FIGURE 7.—*Effects of oven-aging of cellulose nitrate film on its stability at 134.5° C*

ing. A large number of treatments of this kind were investigated in the laboratory by the use of a scratch-resistance test but in no case was sufficient improvement found to warrant their use in documentary practice.

VIII. SUMMARY

Suitable methods of testing photographic films have been developed which, when used in conjunction with accelerated aging by heating, ensure the selection of films having the strength and stability required for various record purposes.

It has been demonstrated that acetate films of both the emulsion and the dye types are suitable for permanent-record use if properly made for the purpose. The properties of such film have been specified to assist in the selection of them. The dye type of film with viscose base has been found to be suitable for reproduction of records

for use in reading rooms, as it has a medium degree of stability. Further evidence of the unsuitability of the nitrate film for record use because of its instability and inflammability has been recorded.

The atmospheric conditions recommended for storage of records contained on paper have been found suitable for film records. These comprise a relative humidity of about 50 percent, a temperature of 70° to 80° F, and air cleansed of acidic gases and dust.

The special precautions required for the storage and use of nitrate film because of its inflammability have been outlined. These comprise storage in metal cans in fire-resistant cabinets of special design within fire-resistant vaults having pressure-relief vents. The results of a study of the size of the pressure-relief vents necessary to prevent explosion of vaults in case of fire indicated that vents larger than those that have been recommended may be desirable.

Special testing procedures for finding the condition of record-bearing films without defacement of images or rendering the films unserviceable otherwise have been described. These are micromethods in which the usual test methods are modified to permit the use of very small test specimens. A special heat test for determining the condition of nitrate film has been found of value.

Precautions to minimize the damage to the photographic images by scratching and handling have been recommended. These are the use of carbon tetrachloride as a cleanser and the use of clean, white cotton gloves in handling the films. Commercial preparations for hardening emulsion to make it more resistant to scratching were investigated, but none of those studied was very effective.

If this information is generally applied in the documentary field to this new form of record material, it will serve to minimize loss of valuable records through use of unstable material, or unsuitable conditions of storage and use.

IX. REFERENCES

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Washington, November 16, 1939.

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