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LAUNDRY "WINTER DAMAGE"

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ABSTRACT

When laundered cotton fabrics are dried out of doors in the winter time in New England, they frequently undergo excessive deterioration of a type called "winter damage." This paper is concerned with an investigation of the causes of "winter damage" and with its prevention.

Analyses of damaged fabrics and experimental work in the laundries and in the laboratory showed that the damage is caused by sulphuric acid which is formed in the damp fabric by the oxidation of atmospheric sulphur dioxide. The oxidation is accelerated and the damage is increased by small amounts of certain substances which may occur in laundered fabrics. Traces of iron, of spent bleach liquor, and of acetic acid were found to have this effect.

A small amount of calcium bicarbonate in the final rinse water of the wash materially reduced the damage, and is recommended as a satisfactory remedy. Precautions should be taken to eliminate iron and spent bleach liquor from the laundered fabrics, and the drying time should be made as short as possible. Antioxidants showed promise of giving protection.

CONTENTS

I. INTRODUCTION

1. NATURE OF THE PROBLEM

For some years past, residents of New England have been harassed by a peculiar kind of disintegration of laundered cotton goods. The outstanding peculiarities are that this kind of deterioration is of general occurrence only in New England and only in the winter. This latter fact has given rise to the name "winter damage." Examples of winter damage are shown in the photographs reproduced in Figures 1, 2, and 3.

Winter damage is unlike other types of deterioration in that its occurrence is largely unpredictable. One garment out of a number in the same wash may be attacked. A new garment is just as liable to be attacked as an old one. Our present experience indicates that the attack of winter damage is limited to cotton, and occurs only when garments are hung outdoors to dry.

Garments laundered in the home are attacked in the same manner as those washed in commercial laundries and sent home to be dried and ironed—the regular "wet wash" service. Probably it is because the laundrymen are organized that the request for assistance in solving this problem came from the Laundryowners' National Association.

2. OUTLINE OF THE INVESTIGATION

Some months were spent in New England studying laundry practice. Through the cooperation of several laundries, many cases of winter damage with their complete histories were examined. Damaged fabrics were analyzed in the laboratory. The rate of deterioration of cotton cloth when laundered and dried outdoors was compared with the rate when the cloth was dried indoors.

On the basis of the information thus obtained, an explanation of how winter damage occurs was developed. This explanation was corroborated by the production of winter damage under artificial conditions in the laboratory. Based on these results a remedy was suggested and put into use in four laundries, where its effectiveness has been indicated by the practical experience of these laundries during the past two winters.

II. DETERMINATION OF THE CAUSE OF WINTER DAMAGE

1. STUDY OF LAUNDRY PRACTICE

While many minor variations were noted at the different plants visited, laundry practice has been pretty well standardized. The "wet wash" is processed in the following steps: Wash with warm alkalized soap suds, wash three times with hot alkalized soap suds, rinse, bleach, rinse four times, sour,[1] blue.

It was found that the water used by New England laundries is relatively pure. The bicarbonate (HCO_3) content was only 6 to 15 parts per 1,000,000, and the calcium carbonate hardness was 0.2 to 2.3 grains per gallon. Occasionally the water was noticeably contaminated with iron,[2] which probably came from corrosion of the heaters and pipes in the laundry.

The odor of chlorine was frequently noticeable in the wash room during the bleaching process. If garments which had been washed and extracted were stored in this room, they might absorb enough chlorine to cause trouble when they are being dried. It will be shown that strong oxidizing agents like chlorine are liable to increase winter damage.

The souring step is introduced in the laundry practice because experience has shown that if a cotton fabric is ironed when in an

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[1] The sour is an acid bath used in one of the last rinses to neutralize traces of alkali remaining in the cloth. It is also claimed by some manufacturers of proprietary sources that their products will remove rust stains.

[2] Iron has been found in water of heating systems of New England laundries between 3.6×10^{-5} molar and 1.4×10^{-5} molar. These conditions are sufficient to effect catalytic action. Even in the cold tap water of Massachusetts 0.4×10^{-5} molar iron has been reported. F. S. Cook, Rôle of Certain Metallic Ions as Oxidation Catalysts, J. Biol. Chem. **10**, p. 289; 1926.

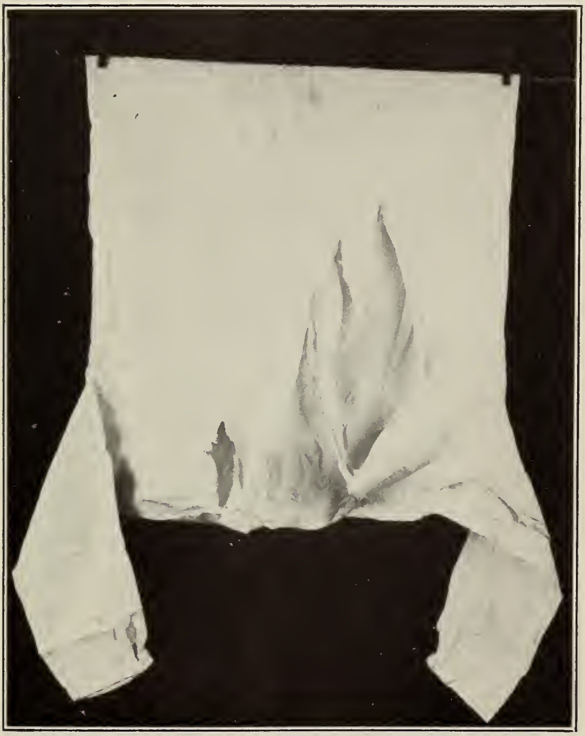

FIGURE 1.—*Typical example of winter damage*

Figure 2.—*Advanced case of winter damage showing discoloration in the region of failure*

alkaline condition, it will eventually turn yellow. A weakly acid [3] (sour) rinse is therefore given to remove the last trace of alkali. Unfortunately, most laundries do not operate under strict technical control, so that, in about half the cases observed, too little sour was added, and the clothes remained slightly alkaline.

2. STUDY OF INDIVIDUAL CASES

The 10 cooperating laundries sent in 907 cases of winter damage, each accompanied with its history. Ten per cent of these proved to be other kinds of deterioration and not winter damage. A study of the authentic cases brought out the fact that winter damage occurs in spots; one or more parts of the garment are seriously weakened or destroyed, but the rest of it remains strong. This strong portion furnished a very convenient blank for analysis.

Winter damage does not necessarily occur all at once. A slight amount of damage may be done at one time, and the final destruction of the goods may not occur until the conditions which cause this type of damage reappear, perhaps, some weeks or months later.

There is a slight, but important,[4] weakening of cotton fabrics every time they are laundered. This "natural deterioration" may add to the deterioration caused by incipient winter damage and thus bring about a failure which will have all the appearance of having been caused by winter damage alone.

In order to get some information about the magnitude of this regular deterioration, and also to ascertain the rôle played by the atmosphere, a bolt of cotton toweling was cut into a number of specimens which were sent to five laundries. The laundries were requested to wash the towels by their customary procedures, to dry half of the specimens with a regular laundry flat-work ironer and the other half by hanging them on a line outdoors, to iron them, and then to repeat the process a number of times. Individual towels were returned to the laboratory after 10, 20, 30, 40, and 50 washings and were tested for tensile strength. The results are shown in Figure 4.

These results show that the treatment given the towels in some laundries is much more severe than in others, but that in every case, drying the towels outdoors results in greater deterioration than when the drying is done on the usual laundry flat-work ironer. Evidently the rôle played by the atmosphere is important.

Chemical examination of garments sent to the laboratory showed several characteristics of winter damage. The badly damaged portion of the garment is practically always more acid in reaction than the remainder, and often it contains a higher proportion [5] of iron in the ash. In no case could the slightest trace of free chlorine be detected. However, the damaged goods usually possessed an odor

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[3] By a weak acid is meant one with a low degree of dissociation, such as acetic acid. However, acids as strong as oxalic are used, but such an acid would usually be buffered to decrease the H-ion concentration.

[4] A report prepared by the Research Laboratory of Applied Chemistry of Massachusetts Institute of Technology indicates that the loss in strength by laundering of collars is distributed as follows: Bleach 40 per cent, soap and soda and rinsing 25 per cent, loss in drying 20 per cent, loss by sour and blue 5 per cent, loss by molder 5 per cent, loss in hot tube 5 per cent. This loss, as well as the losses incurred through normal outside drying, would have to be regarded largely as chemical in nature.

It is well known that a fabric is deteriorated by the action of light, especially between the wave lengths of 400 and 295 μ. Undoubtedly this factor enters where outside drying is concerned. F. W. Aston, Report on the Action of Sunlight on Aeroplane Fabric: Its Nature and Prevention. Advisory Committee for Aeronautics (British) Memoranda 396, pp. 2–5; 1917.

[5] This higher proportion of iron in the ash indicates the possibility of increased catalytic activity. The catalytic action of iron is made use of in industry in the contact process for preparing sulphuric acid from sulphur dioxide and water.

resembling spent bleach liquor, and freshly damaged pieces were found which contained oxidizing material.[6]

In every case of winter damage where the garment had not been laundered subsequent to the occurrence of the damage, the fabric around the obviously affected parts was distinctly more acid than the other parts of the fabric. The damaged portion was so acid as to give a yellow color when treated with a dilute solution (0.0135 g per liter) of brom-phenol blue (indicating a pH of about 3). This high degree of acidity can not be accounted for by the absorption of carbon dioxide from the air.[7] The only other strongly acidic material likely to be extensively present in the atmosphere is sulphur dioxide which in the presence of moisture, may be oxidized to sulphuric acid.

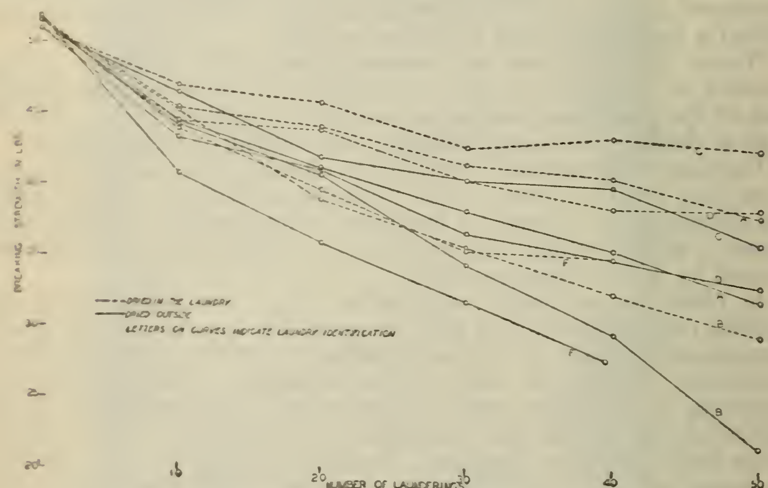

FIGURE 4.—*Effect of laundering on the strength of cotton toweling*

The badly damaged portions of these garments were, therefore, analyzed for sulphuric acid by titration with methyl orange and phenolphthalein, and for sulphates gravimetrically.[8] In practically every case they were found to have a higher content both of free sulphuric acid and combined sulphates than had other portions of the same garments.

In Figure 5 are given the results of typical analyses for free sulphuric acid. It will be seen that the badly damaged portions contain much more acid than the other portions. The amount of sulphuric acid present is small, often between 0.01 and 0.04 per cent, though it may be more than 0.12 per cent. The difference in sulphate content calculated to sulphuric acid between the more damaged and the less damaged portions of affected garments lies between 0.004 and

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[6] Free chlorine may be detected by the use of orthotolidine indicator. The active oxidizing material was not free chlorine but chlorates, ferrates, or ferric salts or even oxidized soap. No free chlorine is present at the time of extraction normally but only the less active oxidized or chlorinated material, as soap, which laboratory experiment has demonstrated as being responsible for the odor of spent bleach liquor.

[7] The pH of moist air subjected to CO_2 of the atmospheric concentration is about 5.7. H. Edna Fawcett and S. F. Acree, The Problem of Dilution in Colorimetric H-Ion Measurements, J. Bacteriology 17, p. 163; 1929.

[8] No free acid could be found in samples of new fabrics similar to those which underwent winter damage deterioration.

FIGURE 3.—*Most advanced type of winter damage in which damaged regions crumble*

FIGURE 6.—*Failure resembling winter damage caused by exposure of an iron-impregnated towel to air containing 1 part per 1,000,000 sulphur dioxide*

0.4 per cent. Barr and Hadfield [9] have shown that even much smaller [10] quantities of sulphuric acid can cause damage to cotton fabrics when they are dried at temperatures such as exist during ironing.

The presence of sulphur dioxide in the atmosphere has been noted by many investigators.[11] The average of more than 1,500 determinations of the concentrations of sulphur dioxide in the vicinity of New York City was 0.265 part per 1,000,000 and a concentration as high as 1.3 parts per 1,000,000 existing for 15-minute intervals has also been found in this vicinity. It has also been established that many metallic salts, particularly those of iron, act as catalysts which accelerate the oxidation of sulphur dioxide to sulphur trioxide, especially in the

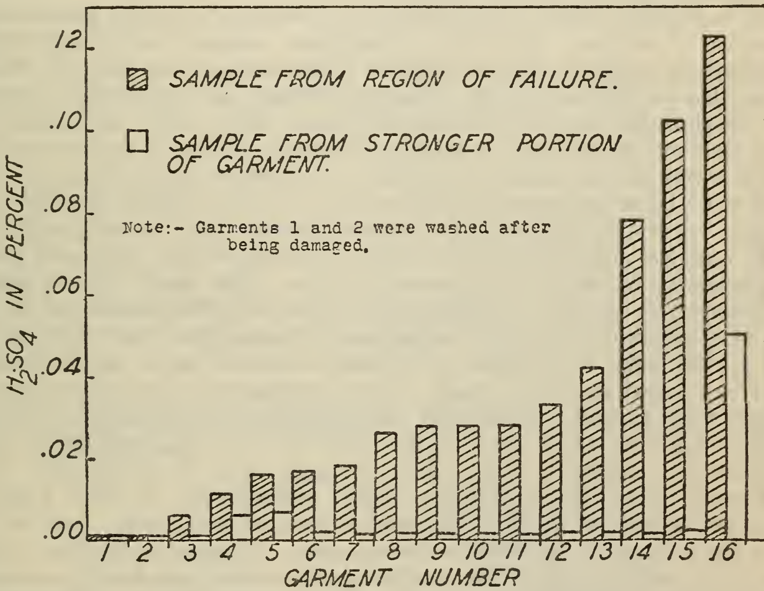

FIGURE 5.—*Typical analyses of winter damaged garments for sulphuric acid*

presence of moisture.[12 13 14] Damp cotton cloth absorbs sulphur dioxide from the air and becomes more and more acid in reaction with time of exposure.

3. THEORETICAL EXPLANATION OF WINTER DAMAGE

The following explanation of how winter damage takes place may be given on the basis of the facts set forth above. The chemical facts may be summarized as follows: Damp cotton absorbs sulphur dioxide

[9] Barr, Guy, and Isabel H. Hadfield. The Effect of Minimal Amounts of Acid on the Strength of Cotton and Linen, Tech. Rept. Advisory Committee for Aeronautics (British), 2, pp. 609–615; 1919–20.

[10] Solutions of N/8,000 H_2SO_4 were found to cause deterioration upon fabrics immersed in them and subsequently heated.

[11] Office of Industrial Hygiene and Sanitation, U. S. Public Health Service, Partial List of References on Pollution of Air by Smoke, Mimeograph Report No. E688.

[12] Cook, S. F., Rôle of Certain Metallic Ions as Oxidation Catalysts, J. Biol. Chem., **10**, pp. 289–312; 1926.

[13] Wilson, L. P., Catalytic Action in the Oxidation of Cellulose, J. Soc. Chem. Ind., **39**, p. 177T; 1920.

[14] Baudisch, O., and Davidson, D., Catalytic Oxidation by Means of Complex Iron Salts, J. Biol. Chem., **71**, pp. 501–508; 1927; C. A. p. 914; 1927.

present in the atmosphere. In the presence of the moisture in the cloth this sulphur dioxide is oxidized to sulphuric acid, rapidly when small amounts of iron or other catalytic agents are present. As the cloth dries, the sulphuric acid becomes concentrated in the regions which dry last.[15] When the cloth is ironed rapid deterioration of the cotton takes place and the cloth becomes weak. In extreme cases it becomes yellowish in color and powders when handled.

Winter damage may be expected to occur, even when there is less sulphur dioxide in the atmosphere than 1 part per 1,000,000, especially (1) when the cloth remains damp and in contact with the atmosphere for a relatively long time, (2) when iron has been absorbed by the cloth, (3) when there are no substances in the cloth which will neutralize the sulphuric acid formed.

It is believed that winter damage occurs only in the winter time because it is then that the atmosphere contains relatively larger amounts of sulphur dioxide because of the smoke from heating plants. It is also in the winter time that cool, damp, overcast days (typical winter-damage days of the laundrymen), days when clothes do not dry well out of doors, are most prevalent. On such days the damp clothes remain in contact with air for relatively long periods of time and thus have an opportunity to absorb more sulphur dioxide than usual. A contributing factor is that on such days air is likely to be still, and the sulphur dioxide, which is heavier than air, has a better opportunity to sink to the ground than on other days. If a garment is washed in water containing iron (derived from corrosion of the heating system) or if it is inadequately rinsed after the wash, it will be particularly susceptible to damage because more sulphuric acid will be formed in it as a result of the presence of the catalysts iron or spent wash liquor. Finally, if the alkaline or buffer salts left in the cloth with the water used in the final rinse are inadequate to neutralize the sulphuric acid, then damage may be expected. It is believed that winter damage occurs principally in New England because the water in New England is exceptionally soft; that is, it is free from bases to neutralize strong acid. In practically every other domestic and industrial use, including the actual laundering operation exclusive of the final rinse, soft water is very much to be desired. Buffer salts which are usually either unnecessary or objectionable serve a useful purpose in the final rinse of "wet wash."

4. ARTIFICIAL WINTER DAMAGE

Further evidence in support of the explanation given above was obtained in the following experiments in which winter damage was produced under artificial conditions. A bolt of cotton toweling was cut into towels which were washed thoroughly and rinsed in distilled water to remove sizing and other superfluous impurities. Towels impregnated with various substances were exposed in a cabinet in air containing 1 part per 1,000,000 of sulphur dioxide when the towels were introduced.[16] A fan kept the air in the cabinet in circulation. All towels were removed from the cabinet once each day, moistened with

[15] The action of the sulphuric acid is first one of hydrolysis in which a number of products, such as dextrins and sugars, are formed. Continued action of the sulphuric acid removes water from the sugars previously formed and thus results in carbonization or charring. Textbook of Cellulose Chemistry, Heuser, West & Esselin, pp. 142-143; 1924.

[16] The effective concentration was much less than 1 part per 1,000,000 because of the absorption by the towels and condensed moisture present on the walls of the case.

distilled water (with calcium chloride-sodium bicarbonate solution in the case of the towels treated with this material), ironed (temperature of iron about 438° F. decreasing about 30° F. during each ironing), again moistened and returned to the cabinet. At the end of 10, 30, and 50 treatments a towel representing each treatment was tested for tensile strength, sulphate content, and free acidity.

The impregnating treatments were: (1) Blanks, towels simply wet with distilled water; (2) towels immersed in a solution of 1.25 g of ferric chloride in 5 liters of water and then in a 0.1 per cent solution of sodium carbonate to precipitate the iron in the towels; (3) towels treated with iron as in (2) and then with a solution of 15 g of sodium bicarbonate and 10 g of calcium chloride in 2.5 liters of water which reacts as a calcium bicarbonate solution; (4) towels bleached with sodium hypochlorite solution containing 0.045 per cent available chlorine at 70° C.

The effect of these treatments on the strength of the toweling is shown in Table 1. The blank retained 60 per cent of its original strength after 50 treatments. The presence of a small amount of iron greatly accelerated the damage to the toweling caused by exposure to sulphur dioxide, the strength being completely gone after 14 treatments. Considerable protection was afforded the iron-impregnated towel by treating it with a calcium chloride-sodium bicarbonate solution (compare experiment 2 and 3 in the table). The towels impregnated with calcium chloride-sodium bicarbonate solution alone deteriorated faster than the blank, but not nearly so fast as the towel containing iron. The bleached toweling (experiment 5 in the table) was not quite so resistant as the unbleached (experiment 1).

TABLE 1.—*Breaking strength of toweling treated with various substances when moistened and exposed to air containing 1 part per 1,000,000 of sulphur dioxide for 24 hours and ironed*

Experiment No.	Towels treated with (see text)—	Breaking strength in per cent of original after: Number of exposures—		
		10	30	50
1	Nothing	96	87	60
2	Iron	91	0	0
3	Iron and calcium bicarbonate	95	80	45
4	Calcium bicarbonate	100	76	37
5	Bleach	91	74	54

The sulphate and the free acid content of the exposed towels was observed to increase with number of exposures. The blank contained 0.02 per cent free acid and 0.59 per cent sulphates (reported as H_2SO_4), after 50 exposures, The iron-impregnated towel contained 0.03 per cent free acid and 0.3 per cent sulphates after only 10 exposures. The iron-impregnated towel which was given the additional treatment with calcium bicarbonate solution contained 0.02 per cent free acid after 50 treatments and 0.54 per cent sulphates.

The damage to the toweling in these experiments is in every way like winter damage occurring under natural conditions. Figure 6 shows the failure of an iron-impregnated towel after exposure to air containing 1 part per 1,000,000 sulphur dioxide.

Similar experiments to those described above were carried out exposing the fabrics on the roof of the Industrial Building, National Bureau of Standards. The results were, in general, similar to those obtained in the cabinet exposures though the decrease in strength was much less, and smaller amounts of acid and sulphates accumulated in the fabrics.

Another series of experiments was carried out in which towels containing small amounts of soap, bleach liquor, etc., were exposed in the cabinet to air containing 1 part per 1,000,000 of sulphur dioxide according to the procedure already described.

The treatments were: (1) Blank, toweling simply wet with distilled water, (2) towels immersed in water containing 0.25 per cent tallow soap, then in a sodium hypochlorite bleach solution containing 0.025 per cent available chlorine, and wrung out; (3) towels treated as in (2) and then rinsed in a 2 per cent solution of acetic acid; (4) towels immersed in a solution of 10 g of sodium chlorate (an oxidizing agent) in 3 liters of water; (5) towels immersed in a 0.026 per cent solution of ferric chloride, then in a 0.1 per cent solution of sodium carbonate to precipitate the iron in the towels, and finally in a 0.33 per cent solution of sodium chlorate.[17]

The effect of these treatments on the strength of the toweling after 17 exposures, each followed by moistening and ironing, is shown in Table 2. The laundryowners' attention is particularly called to experiments 2 and 3 which indicate that traces of soap and bleach liquor in the towel decrease its ability to withstand the action of sulphur dioxide and that a final rinse with acetic acid makes matters very much worse. The results of experiments 4 and 5 are further evidence that strong oxidizing agents increase the action of sulphur dioxide.

TABLE 2.—*Breaking strength of toweling treated with various substances when moistened and exposed to air containing 1 part per 1,000,000 of sulphur dioxide for 24 hours and ironed*

Experi-No.	Towels treated with (see text)—	Breaking strength in per cent of original after 17 exposures
1	Nothing	92
2	Soap and bleach	44
3	Soap, bleach, and acetic acid	9
4	Sodium chlorate	[1] 30
5	Iron and sodium chlorate	20

[1] The sodium chlorate-treated towel would have been weakened more if it had been made distinctly acid before exposure because the sodium chlorate would then have been a more active oxidizing agent. This principle is demonstrated in experiments 2 and 3 in above table.

III. REMEDIES SUGGESTED

1. ALKALINE RINSES

This work indicates that it should be possible to materially decrease or prevent winter damage by introducing an alkali into the cloth after each laundering, in order that any sulphuric acid may be

[17] Concentrations of soap and bleach correspond to laundry practice. The concentration of iron was sufficient to insure catalytic action. Arbitrary amounts of the other chemicals were used. In all cases objectionable excesses were avoided.

neutralized. Practical experience has shown that sodium carbonate left in the garments makes it impossible to produce that brilliant whiteness which is so generally desired. Although the "yellowing" produced by such alkalies, as sodium carbonate, may have little effect on the strength of the fabric, it has such an important effect on the appearance that they must be carefully avoided. To this end, general laundry practice calls for a final rinse with a mild acid (sour), and many of the types of bluing in general use will work only in a weakly acid solution.

The use of sodium silicate to keep iron from the fabric and to exert a neutralizing action in the fabric was first tried as a possible preventive of winter damage. However, it was found in the case of the particular silicate being tried, that if an adequate quantity was used to be effective, discoloration occurred. Hence, more extensive trials with this material were discontinued.

A mixture formed by adding to the rinse calcium chloride and then sodium bicarbonate was found to be effective. It is very mildly alkaline in reaction, is soluble at the dilution prepared, and apparently does not cause discoloration if used properly. There is no cumulative building up of the carbonate in the fabric as there is of sodium silicate when this latter material is used.

2. INHIBITING AGENTS

The above explanation of winter damage suggests that the damage would be prevented by impregnating the garment with an inhibiting agent. By means of such a chemical, it would be possible to keep the sulphur dioxide from becoming oxidized to sulphur trioxide, and, since sulphur dioxide is a gas having only a limited solubility in water, the drying and ironing of the garment would not concentrate the sulphurous acid (formed when sulphur dioxide dissolves in water) to the point where it could attack cotton.

Many different inhibiting agents were tried. Towels impregnated with iron as in the previous experiments were dipped in solutions of inhibiting agents (adjusted to the same pH with methyl red), exposed to the action of sulphur dioxide, ironed, and the process repeated. Several chemicals were found which afforded protection to the fabric. Sodium oxalate and resorcinol were among the best.

This is one more bit of evidence in substantiation of the cause of winter damage, and the laboratory work as completed indicates that further study with inhibiting agents might result in formulating the most efficient means of decreasing winter damage. Inasmuch as the calcium chloride-sodium bicarbonate treatment has practical advantages and fewer possible complications, it was selected for trial in the laundries.

3. THE REMEDY RECOMMENDED

Certain conclusions having been reached as a result of the laboratory work, it was appropriate to try them out on a practical scale. Cooperative arrangements were made with four laundries in New England, and the following procedure was put into effect, under carefully controlled conditions:

After the garments have been washed, rinse thoroughly.

If a sour is used, follow it with at least one rinse with plain water.

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Apply the bluing in the usual way, running the wheel (washing machine) for three mintues. The dye Colour Index No. 246 [18] is a satisfactory bluing for use in alkaline solution. Bring the water level to 6 to 8 inches for a 42 by 84 inch wheel. Add 2 pounds of calcium chloride dissolved in a pail of water, and run for two mintues. Add 3 pounds of sodium bicarbonate dissolved in a pail of water and run for five minutes.[19] Remove the goods, and extract in the centrifuge in the usual way. Caution the customer to dry the garments quickly, and particularly not to let them hang out of doors over night.

The quantities of reagents given above are approximately correct for the size of wheel mentioned. Since too great alkalinity is almost as bad as not enough, the use of this process requires careful control of the amounts of reagents used. The final alkalinity should be such that not less than 6 nor more than 10 drops (20 drops = 1 ml.) of tenth normal sulphuric acid are required to neutralize 5 ml of the rinsing water using methyl red as the indicator.

4. STATEMENTS FROM THE LAUNDRIES

Statistics were received weekly during the winter of 1928–29 from eight laundries not using this treatment as well as from one using it. The laundry having the greatest damage reported an average of 50 pieces (approximate weight per piece = 0.4 pound) per 5,000 pounds of goods and the average for all laundries not using the treatment was 10 pieces for every 5,000 pounds of goods. In the laundry where the calcium bicarbonate final rinse was used, the average for the season was only one piece for every 5,000 pounds of goods. The opinion of the three other laundries using the treatment, but not sending in weekly reports concerning this rinse is given in one production manager's report in which he states that "the treatment materially and immediately reduced" his winter damage claims and "continued to be effective as long as used."

IV. PATENT

It will be noted from the above that the final stage of this investigation was completed during April, 1929. On April 9, 1929, a patent for a method of protecting fabric was granted to Robert A. Pahir and assigned to H. Kohnstamm & Co. (Inc.). The patent number is 1708519, and the application was filed on March 9, 1925. Without assuming any legal responsibility for the statement, it would seem that the calcium bicarbonate treatment recommended herein is covered by this patent.

V. ACKNOWLEDGMENT

The author gratefully acknowledges the cooperation of the Massachusetts Laundryowners' Association and its member laundries. He is especially indebted to the Massachusetts Institute of Technology for laboratory space and for chemicals and to H. O. Forest and H. J. MacMillan, of the institute staff, for helpful information. F. H. Guernsey, of the Cowles Detergent Co., and R. A. Phair, of the H. Kohnstamm Co., furnished much valuable data.

WASHINGTON, January 26, 1931.

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[18] "Colour Index" of the British Society of Dyers and Colourist; 1928. See the current Yearbook of the American Association of Textile Chemists and Colorists for the American Manufacturers of this dye and the names under which they sell it.

[19] The ratio is approximately that of the equivalent weights of the chemicals used. The amounts used correspond to the concentrations of bicarbonates and calcium salts frequently found in natural waters.