THE JOURNAL OF THE

TEXTILE INSTITUTE

TRANSACTIONS

7—THE ACTION OF PHENOL ON WOOL

By T. BARR and J. B. SPEAKMAN

It is already known that wool dissolves with decomposition in hot phenol,[1] but the fact that wool fabrics undergo rapid and pronounced shrinkage when they are immersed in melted phenol appears to have been overlooked. This observation was made during the course of another investigation, and it seemed to merit further study so that the cause of shrinkage could be elucidated and its practical applications developed.

EXPERIMENTAL

In the original experiment to which reference has just been made, a pattern (2·67 g. air-dry*) of all-wool flannel was immersed in phenol (100 g.) for 15 minutes at 80° C. When the pattern was removed, it was found to have shrunk 27·1 per cent. in area, and even after an overnight wash in running water, the residual shrinkage was 10·9 per cent. Before attempting to discover the cause of shrinkage, experiments were carried out to define the optimum conditions for its occurrence by studying the influence of the time and temperature of treatment and the effect of adding varying amounts of water to the phenol. The work was carried out with fabric A, which had the characteristics shown in Table I, but two other fabrics, B and C, were also used for the purpose of discovering the extent to which shrinkage is influenced by the structure of the fabric.

Table I

	Fabric A	Fabric B	Fabric C
Count of warp yarn	28 skeins	16 skeins	2/36s worsted
Count of weft yarn	28 ,,	20 ,,	2/36s ,,
Ends per inch	34	32	72
Picks per inch	34	35	60
Weight per sq. yd. (oz.)	5·40	8·51	7·40

Factors influencing the Extent of Shrinkage

(1) *Time of treatment.*—Five patterns of fabric A, each weighing 2·5 g. air-dry, were immersed together in 250 g. phenol at 50° C. To facilitate shrinkage measurements, a 10 cm. square was marked out on each pattern in coloured cotton, the area of the square being re-measured when the pattern was removed from the phenol, and again after it had been washed in three changes of water at 35° C., using 500 ccs. each time, followed by running water for 30 minutes. Patterns were removed from the phenol at intervals, and the results of the shrinkage measurements are given in Table II, illustrated by Fig. 1.

*Throughout this paper, the term " air-dry " implies conditioning at 65 per cent. relative humidity and 72° F.

Table II

Time of treatment (minutes)	Percentage shrinkage in area	
	In phenol	After washing
1·0	6·9	5·0
2·5	9·7	7·8
5·0	15·4	9·7
10·0	22·6	16·3
15·0	24·3	15·4

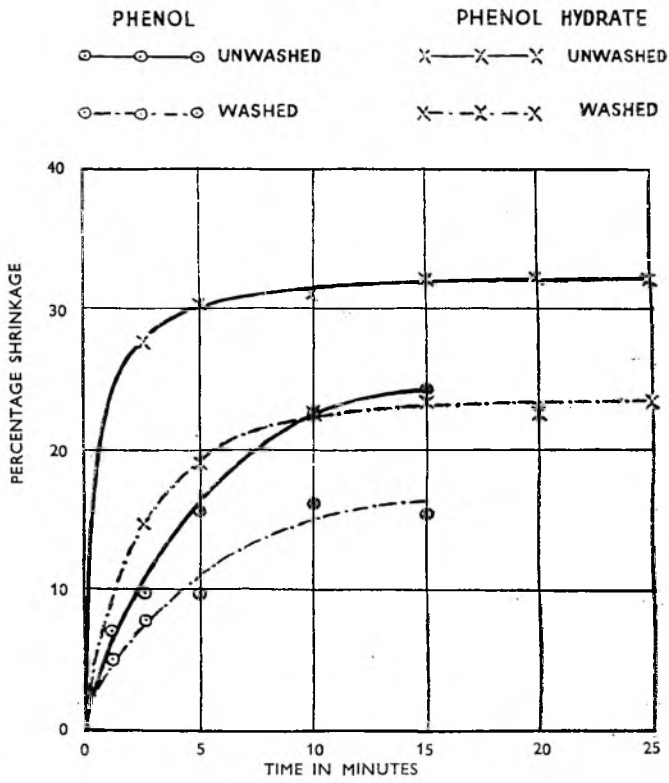

Fig. 1

Shrinkage appears to be fairly complete in 15 minutes, and the rapidity of the process was confirmed by further experiments with a mixture having the composition of phenol hydrate[2] $[(C_6H_5OH)_2H_2O]$. In this case, each 2·5 g. pattern, on which a 10 cm. square had been marked out in coloured cotton, was immersed in 100 g. of the mixture at 80° C. Patterns were treated for times varying from 2·5 to 25 minutes, and the results of the shrinkage measurements are given in Table III, illustrated by Fig. 1.

Table III

Time of treatment (minutes)	Percentage shrinkage in area	
	In phenol hydrate	After washing
2·5	27·7	14·5
5·0	30·3	19·0
10·0	31·1	22·6
15·0	32·0	23·4
20·0	32·0	22·6
25·0	32·0	23·4

(2) *Temperature of treatment.*—Squares were marked out on 2·5 g. patterns of fabric A in the usual manner, and the patterns were then treated with the phenol hydrate mixture for 15 minutes at different temperatures. Each pattern was separately immersed in 100 g. of the mixture, and the extent of shrinkage was measured before and after washing. The results are summarised in Table IV, illustrated by Fig. 2.

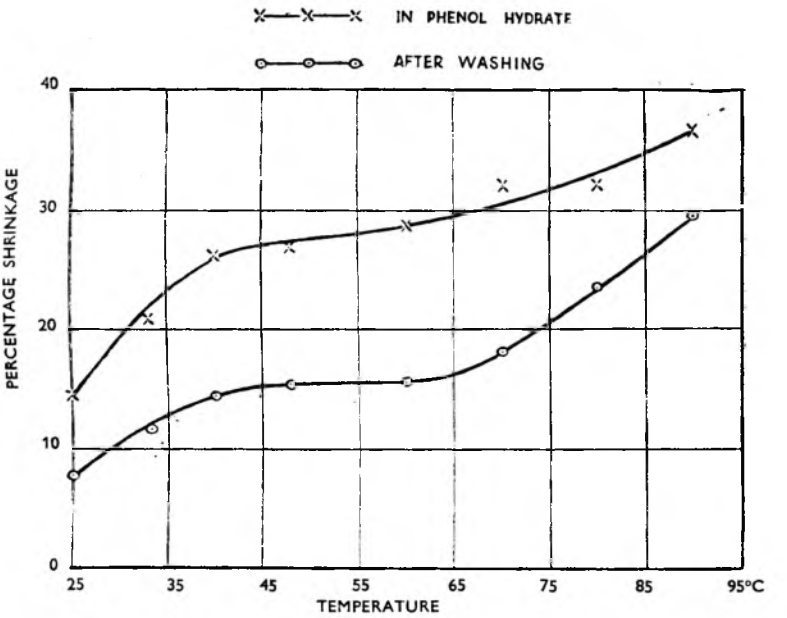

Fig. 2

Table IV

Temperature of treatment (° C.)	Percentage shrinkage in area	
	In phenol hydrate	After washing
25	14·4	7·8
33	20·7	11·6
40	26·2	14·5
48	26·8	15·3
60	28·6	15·4
70	32·0	18·0
80	32·0	23·4
90	36·7	29·5

As shown in Fig. 2, the extent of shrinkage first increases with rise of temperature up to 40° C., then remains practically constant between 40° and 60° C., and finally again increases up to 90° C.

(3) *Structure of the fabric.*—To discover whether the structure of a fabric affects the extent of its shrinkage in phenol, 2·5 g. patterns of the fabrics described in Table I were immersed in 100 g. phenol for 15 minutes

Table V

Fabric	Percentage shrinkage in area	
	In phenol	After washing
A	24·4	10·6
B	18·3	7·8
C	18·1	5·9

at 50° C. The areas of the marked squares were re-measured before and after washing, and the shrinkages are shown in Table V.

All the fabrics contract in phenol, and in all cases part of the shrinkage persists after washing, but it is evident that the structure of a fabric has a considerable influence on both the initial and final shrinkages.

(4) *Addition of water to the phenol.*—Patterns of fabric A, each weighing 2·5 g. air-dry, were marked out with 10 cm. squares in the usual manner and then immersed for 15 minutes at 80° C. in 100 g. of the mixtures shown in Table VI. The areas of the squares were re-measured when the patterns were removed from the mixtures, after they had been given the usual wash, and after a final prolonged wash of 24 hours in running water. A summary of the observed shrinkages is given in Table VI, illustrated by Fig. 3.

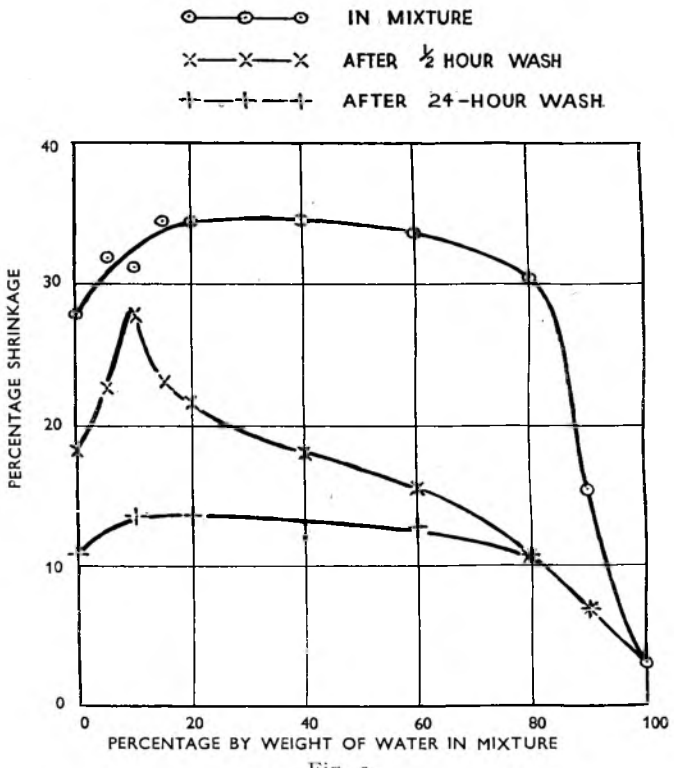

Fig. 3

Table VI

Percentage by weight of water in mixture	Percentage shrinkage in area		
	In mixture	After ½-hour Wash	After 24-hour wash
0	27·8	18·1	10·8
5	32·0	22·6	—
10	31·2	27·8	13·5
15	34·4	23·1	—
20	34·4	21·6	13·5
40	34·4	18·1	12·6
60	33·6	15·4	12·6
80	30·4	10·7	10·8
90	15·4	6·9	6·8
100	Soaked for 24 hours at room temperature 3·2		

The shrinkage of the unwashed fabric increases with increasing water content of the mixture up to 15 per cent., and then remains approximately constant until the water content is about 60 per cent., beyond which point there is a rapid fall. After a ½-hour wash, however, shrinkage is most pronounced in the case of a fabric treated with a mixture containing just under 10 per cent. of water, corresponding to the existence of the hydrate $(C_6H_5OH)_2H_2O$. If the latter should function as a weak dibasic acid, causing intense swelling of the fibres, shrinkage might well be due to this cause, though it provides no immediate explanation of the large amount of shrinkage which persists after a 24-hour wash and all the phenol is removed. Before proceeding to study the cause of shrinkage, however, the general validity of the preceding observations was confirmed by similar experiments with fabrics B and C. The results are given in Table VII.

Table VII

Percentage by weight of water in mixture	Percentage shrinkage in area		
	In mixture	After ½-hour wash	After 24-hour wash
	Fabric B		
0	27·8	10·8	10·8
5	28·6	14·5	10·8
10	30·3	13·6	10·8
15	30·3	10·7	10·8
20	31·1	10·7	8·8
40	28·6	9·8	8·8
60	27·8	7·9	7·9
80	25·2	6·8	6·8
90	9·7	5·0	5·0
100	Soaked for 24 hours at room temperature		2·0
	Fabric C		
0	22·6	8·8	7·9
5	23·5	10·6	7·9
10	24·4	10·6	7·9
15	23·6	9·8	8·9
20	23·6	7·9	6·9
40	23·6	8·9	6·9
60	22·7	7·9	6·9
80	20·8	6·9	6·9
90	16·4	5·0	5·0
100	Soaked for 24 hours at room temperature		3·9

The Cause of Shrinkage

From first principles, it is evident that the shrinkage of wool fabrics in phenol and mixtures of phenol and water must be due to one or other of the following causes: length contraction of individual fibres, lateral swelling of the fibres, or relative movement of the fibres, as in milling.

The first of these possibilities was examined by determining the length contraction of wool fibres in phenol. Single fibres of 64s merino wool were mounted in stainless steel setting frames[3] and their air-dry lengths measured by means of a travelling microscope. After the fibres had been slackened by screwing down the upper grips, the frames were immersed in phenol at 50° C. for 5 minutes. The fibres were then drawn just taut and their lengths re-measured in the phenol. The frames were afterwards transferred to running water, and when the slackened fibres had been washed for 15 minutes, they were allowed to dry in room air before re-measuring their lengths. Typical results are given in Table VIII.

Table VIII

Original length in air (cms.)	Length in phenol (cms.)	Contraction (%)	Length in air after washing (cms.)	Contraction (%)
4·420	4·260	3·6	4·425	Nil
5·360	5·195	3·1	5·360	Nil
5·880	5·540	5·8	5·875	Nil

Although length contraction of wool fibres in phenol is much too small to account for the whole of the shrinkage observed with fabrics, its contribution is not negligible. Further, although the fibres return to their original length on being washed in water, length contraction in phenol may play some part in determining the permanent shrinkage of washed, phenol-treated fabrics if there is any relative movement of fibres during phenol treatment and washing.

A first indication that the second factor, lateral swelling of the fibres, might play some part in causing shrinkage of wool fabrics in phenol, was obtained by determining the extent to which the shrinkage of a yarn is dependent on its twist. For this purpose, 10-inch lengths of a 1/48s merino yarn were untwisted in a twist-testing instrument and different, known, amounts of twist were then inserted by hand. Short lengths of these yarns were mounted in stainless steel setting frames, and after their lengths had been measured by means of a travelling microscope, the yarns were slackened and immersed for 15 minutes at 50° C. in a solution having the composition of phenol hydrate. The taut lengths of the yarns were re-measured in the solution and again after 15 minutes' washing in running water, followed by drying. Shrinkage data are given in Table IX.

Table IX

Twist (turns/inch)	Percentage shrinkage In phenol hydrate	After washing
10	10·0	3·7
	11·6	3·2
15	11·4	6·3
	10·2	4·5
20	12·4	5·8
	11·6	8·4
25	13·0	7·5
	17·0	8·8

Like fabric, but unlike single fibres, the phenol-treated yarns show a considerable contraction after being washed and dried, in agreement with the earlier suggestion that relative movement of fibres may take place during the phenol treatment and subsequent washing of fabrics. As the shrinkage of the yarns in phenol increases with the amount of twist inserted, it seemed probable that an important cause of shrinkage is lateral swelling of the fibres. Swelling measurements were therefore undertaken, using lightly pigmented human hair instead of wool, so that the fibres would be clearly visible in the phenol solution.

Single fibres of human hair, which had been purified by extraction with alcohol and ether in a Soxhlet apparatus, followed by washing in distilled water, were mounted between the pairs of clamps of a brass apparatus, which fitted inside an optical cell made of glass. The clamps were so arranged that each fibre could be drawn taut at will, and then rotated bodily about a vertical axis to allow the major and minor axes of the elliptical cross-section to be measured. For this purpose, an image of the fibre was thrown on to a vertical screen by means of a projection microscope, the magnification

being kept constant throughout the whole series of experiments. After measuring the major and minor diameters of each fibre in room air, the glass cell was filled with distilled water and the diameters re-measured at 22° C. The cell was then emptied, dried and re-filled with phenol hydrate, in which the fibres were allowed to stand for 18 hours at 22·2° C. (humidity room). The swelling of the fibres in the solution was then determined at various temperatures, the cell being heated by means of a resistance coil enclosed in a glass tube and immersed in the solution, which was well stirred throughout the experiment. If a and b are the major and minor diameters of the fibres, respectively, swelling was calculated as the percentage increase in the value of $\sqrt{ab}$, referred to its value in water at 22° C. The results are summarised in Table X, illustrated by Fig. 4.

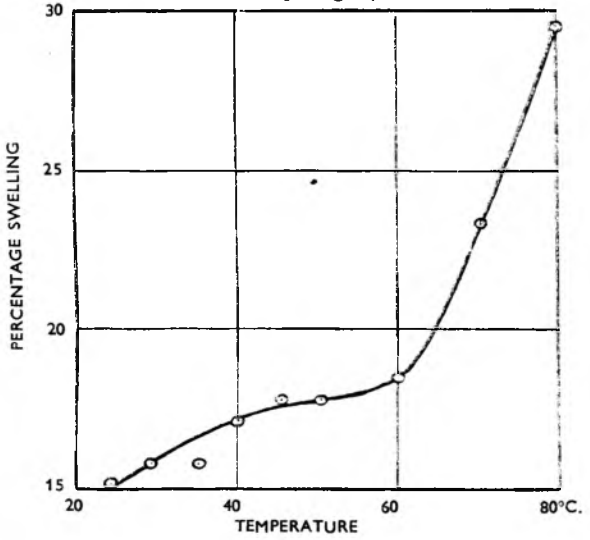

Fig. 4

Table X

Medium	Temperature (° C.)	Fibre 1				Fibre 2	Fibre 3
		a	b	$\sqrt{ab}$	Swelling (%)	Swelling (%)	Swelling (%)
Room air ...	—	16·9	10·2	13·1	—	—	—
Water	22	17·6	12·2	14·6	—	—	—
Phenol hydrate ...	24	21·0	13·4	16·8	15·1	10·7	19·5
,, ,, ...	29	21·3	13·4	16·9	15·8	—	—
,, ,, ...	35	21·4	13·3	16·9	15·8	—	—
,, ,, ...	40	21·8	13·4	17·1	17·1	—	—
,, ,, ...	45	22·0	13·4	17·2	17·8	—	—
,, ,, ...	50	22·0	13·3	17·2	17·8	14·1	22·6
,, ,, ...	60	22·2	13·3	17·3	18·5	—	—
,, ,, ...	70	22·7	14·3	18·0	23·3	—	—
,, ,, ...	80	24·0	14·8	18·9	29·5	20·6	33·6

Since the curves of Figs. 2 and 4 are similar in shape, it seems clear that the shrinkage of wool fabrics in a solution having the composition of phenol hydrate is governed to a large extent by the pronounced lateral swelling of the component fibres, in agreement with the observations on yarns containing different amounts of twist.

An interesting feature of the results for Fibre 1 in Table X is the constancy of the minor diameter b between 24° and 60° C. This observation was confirmed by further measurements on a fibre from a different supply

of hair, the procedure being exactly the same as before, except that measurements at different temperatures were commenced half-an-hour after the fibre had been immersed in phenol hydrate at 26·5° C. The results are given in Table XI.

Table XI

Medium	Temperature (° C.)	*a*	*b*	$\sqrt{ab}$	Swelling (%)
Water	22·0	37·0	28·0	32·2	—
Phenol hydrate	26·5	40·0	30·1	34·6	7·5
,, ,, ...	31·0	41·5	30·0	35·3	9·6
,, ,, ...	35·0	43·0	30·2	35·9	11·5
,, ,, ...	40·0	45·0	30·0	36·8	14·3
,, ,, ...	50·3	47·0	30·1	37·6	16·8

On being washed in running water for 18 hours, after the completion of the above measurements, the fibre returned exactly to its original diameter in water at 22·0° C., confirming the suggestion already made that the shrinkage which persists after phenol-treated yarns and fabrics have been washed must be due to relative movement of the component fibres during phenol-treatment and washing.

So far, however, no direct evidence has been obtained in support of the third possibility that part of the shrinkage of wool fabrics in phenol is due to relative movement of the component fibres. If such movement does occur, repeated treatment with phenol should cause a progressive increase in the shrinkage of a fabric, especially the shrinkage permanent to washing. A 2·5 g. (air-dry) pattern of fabric A, on which a 10-cm. square had been marked out in coloured cotton, was therefore immersed in 100 g. phenol for 15 minutes at 80° C. After the pattern had been washed in three changes of water at 35° C., followed by running water for 30 minutes, it was centrifuged and the area of the marked square re-measured. The whole process was carried out four times in succession and shrinkage data are given in Table XII.

Table XII

Number of treatments	Percentage shrinkage in area	
	In phenol	After washing
1	28·8	18·5
2	33·4	27·2
3	35·1	30·4
4	36·2	33·4

In the light of these results, there can be little doubt that the shrinkage of wool fabrics in phenol and phenol-water mixtures is due to length contraction and lateral swelling of the component fibres, accompanied by their movement relative to one another during treatment and subsequent washing. Lateral swelling seems to be the most important of these factors, and since the greatest shrinkage is produced by concentrated aqueous solutions of phenol, it seems clear that the phenol functions as a weak acid. The extent to which wool fabrics can be shrunk by simple immersion in concentrated solutions of other weak acids was therefore examined.

(*a*) *Formic Acid.*—It is already known[4] that wool fibres undergo pronounced lateral swelling in 98 per cent. formic acid at 22·2° C., and the 90 per cent. formic acid used in the following experiments was found to increase the diameter ($\sqrt{ab}$) of human hair by 16·3 per cent. at 22·2° C., compared with the diameter in water at the same temperature.

The rate at which shrinkage takes place in 90 per cent. formic acid was first examined by immersing each of a number of 2·5 g. (air-dry) patterns

of fabric A, on which 10-cm. squares had been marked out, in 100 ccs. of the solution for a specified time at 50° C., washing in three changes of water at 35° C., followed by running water for 30 minutes, and then re-measuring the areas of the marked squares. Shrinkage data are given in Table XIII.

Table XIII

Time of treatment (minutes)	Percentage shrinkage in area	
	In formic acid	After washing
5	19·0	4·0
10	19·9	5·0
15	20·8	7·9
20	21·7	6·9
25	21·7	9·8

As in the case of phenol, shrinkage takes place extremely quickly, and the influence of the temperature of treatment on the extent of shrinkage was next examined by immersing each of a number of 2·5 g. patterns of fabric A in 100 ccs. of 90 per cent. formic acid for 15 minutes at a specified temperature. After treatment, the patterns were washed in the usual manner and shrinkage data are given in Table XIV.

Table XIV

Temperature of treatment (°C.)	Percentage shrinkage in area	
	In formic acid	After washing
25	19·0	6·0
30	19·0	6·9
40	20·0	7·8
50	19·9	6·9
70	21·7	7·8

Unlike that of phenol, the shrinking effect of formic acid is almost independent of the temperature of treatment, and although formic acid and phenol are generally very similar in their behaviour, phenol is far more effective in causing shrinkage at high temperatures.

(*b*) *m-Cresol.*—The shrinkage of fabric A in *m*-cresol and a mixture of *m*-cresol and water was examined by treating patterns for 15 minutes at 80° C. in the usual manner, but the time of washing in running water was increased to 2 hours on account of the lower solubility of *m*-cresol. The results are summarised in Table XV.

Table XV

Percentage by weight of water in mixture	Percentage shrinkage in area	
	In mixture	After washing
0	27·6	9·8
10	27·8	14·4

m-Cresol is very similar in its behaviour to phenol, and the preceding experiments with phenol, *m*-cresol and formic acid confirm the suggestion that the shrinkage of wool fabrics in such reagents is characteristic of concentrated solutions of weak acids in general. Attention was next turned to the practical application of the shrinkage phenomena.

Practical Applications

It is obvious from the results of Table XII, that if a wool fabric were passed at open width through hot phenol and water, alternately, in a succession of tanks fitted with squeeze rollers, rapid and pronounced shrinkage

would be the result. A continuous process of this type might have special advantages with particular types of fabric, especially those in which pronounced shrinkage without the development of cover is desired. In general, however, the difficulty of recovering phenol from the wash water would render the process uneconomic, and attempts were therefore made to fix the primary shrinkage of the fabric in phenol by means of steam. If successful, a method of this type would lend itself very well to the production of crêpes, and the effect of steaming fabric on which phenol hydrate had been printed was therefore examined.

Phenol hydrate was printed in two sets of parallel lines at right angles on a sample of fabric A, the lines being about $\frac{1}{8}$-inch wide and $\frac{1}{2}$-inch apart. The pattern was then exposed to a current of dry steam at 117° C. for 10 minutes. On removal, it showed a pronounced blister effect, which was permanent to washing in water at 40° C. Equally successful results were obtained when a printed pattern was exposed to steam at 102° C. for 10 minutes, and the lower temperature would be preferred in practice because it leaves the wool almost unaffected as regards strength, whereas degradation is severe at 117° C. Strength measurements were made on strips of fabric, each 12-in. × $1\frac{1}{2}$-in., in which coloured cotton indicator threads had been inserted at a distance of 1-in. from each end. The strips were impregnated with phenol hydrate at room temperature, squeezed between rollers, and then steamed for 10 minutes at 117° or 102° C. Ten strips were treated at each temperature, and after being rinsed in water at 40° C. they were exposed for three days, with ten untreated strips, to an atmosphere at 65 per cent. relative humidity and 22·2° C. Determinations of strength and extensibility were carried out under the same conditions, with the strips gripped at the indicator threads, and the results are given in Table XVI.

Table XVI

Pattern	Percentage Shrinkage in area	Breaking Load (kg.)	Extension at Break (%)
Untreated	—	9·4 ± 0·5*	32·1 ± 1·5*
Steamed at 117° C. ...	60	8·6 ± 1·4*	13·8 ± 1·9*
Steamed at 102° C. ...	56	9·2 ± 0·6*	28·8 ± 3·5*

* Average deviation.

Highly satisfactory crêpes can thus be produced by printing wool fabrics with phenol hydrate, which may be thickened with poly-ethyl acrylate or other suitable agents when specially well-defined effects are desired, followed by steaming at 102° C. for 10 minutes. The success of the process seems to depend on the effect of heat in accentuating the shrinking power of phenol, and the action of steam in promoting setting reactions in the fibres of the contracted fabric before the phenol evaporates. As the conditions are obviously rather critical, it is not surprising that no trace of a crêpe effect was obtained when a fabric printed with formic acid was steamed for 10 minutes at 102° C., for the shrinking effect of formic acid is scarcely affected by rise of temperature, and setting reactions are hindered by strong acids.[5] In the light of this result, it seemed desirable to examine the crêping power of a series of weak acids so as to establish the maximum strength of acid it is permissible to use.

The acids chosen for examination were all phenols—*m*-cresol, phenol, resorcinol, *p*-chlorophenol, 2:4:5-trichlorophenol and 2:4-dichlorophenol. In printing, *m*-cresol was applied without dilution, phenol was used as the hydrate, and the chlorophenols were mixed with $\frac{1}{2}$-mol. of water and just sufficient alcohol to give clear liquids at room temperature. Resorcinol, which is already known[6] to give crêpe effects under conditions similar to

those described above, was mixed with 1 mol. of water and the mixture clarified with alcohol. After the patterns had been printed with the various reagents, they were steamed for 10 minutes at 102° C. and then rinsed in water at 40° C. The results are given in Table XVII, which includes values for the dissociation constants of the compounds used.

Table XVII

Reagent	Dissociation constant	Crêpe effect
m-Cresol	$9{\cdot}8 \times 10^{-11}$ (25° C.)[7]	Good
Phenol	$1{\cdot}09 \times 10^{-10}$ (25° C.)[8]	Good
Resorcinol	$3{\cdot}7 - 4{\cdot}0 \times 10^{-10}$ (18° C.)[9]	Good
p-Chlorophenol	$6{\cdot}6 \times 10^{-10}$ (25° C.)[10]	Good
2 : 4 : 5-Trichlorophenol ...	$4{\cdot}3 \times 10^{-9}$ (25° C.)[11]	Slight
2 : 4-Dichlorophenol ...	$1{\cdot}8 \times 10^{-8}$ (25° C.)[10]	Very slight

The dissociation constant of the phenol should obviously not exceed 1×10^{-9} if it is to be really effective in producing crêpe effects and permanent shrinkage under the influence of dry steam. Even when the phenol has a satisfactory dissociation constant, a crêpe effect is not obtained if the fabric to which it is applied contains a strong acid, because the latter inhibits setting reactions. This fact was revealed during the course of an attempt to crêpe a chlorinated fabric. After phenol hydrate had been applied, the fabric was steamed for 10 minutes at 117° C., but no crêpe was obtained. The result was particularly disappointing because crêpe effects in chlorinated wool are likely to possess special value, but the chlorinated fabric was found to be slightly acid (*p*H 4). When the process was repeated with a second pattern, which had been immersed in 0·25 per cent. sodium carbonate solution for 15 minutes at room temperature, washed in running water for 30 minutes, and then dried, the resulting crêpe was excellent. Crêpe effects can thus be obtained with "unshrinkable" as well as ordinary fabrics, provided they are neutralised before applying a phenol with a dissociation constant less than 1×10^{-9} and steaming at 102° C.

SUMMARY

Wool fabrics undergo rapid and pronounced shrinkage when they are immersed in concentrated aqueous solutions of phenol or melted phenol. Shrinkage is complete in 15 minutes and increases in extent with increasing temperature of treatment up to 90° C. at least. When the treated fabric is washed in water, it tends to revert to its original area, but part of the shrinkage—about a third—persists after a 24-hour wash in running water.

Shrinkage appears to be due mainly to the pronounced lateral swelling of wool fibres in concentrated aqueous solutions of phenol, accompanied by a slight length contraction. In addition, there must be some relative movement of the fibres during phenol treatment and washing, because part of the shrinkage of a fabric is permanent to washing, whereas fibres swollen and contracted in phenol revert to their original dimensions when the phenol is removed.

When a fabric is subjected to repeated treatment with hot phenol and water, alternately, almost the whole of the initial shrinkage in phenol can be made permanent to washing, presumably owing to relative movement of the fibres. A process of this type might have special advantages in cases where pronounced shrinkage is desired without the development of cover, but the difficulty of recovering phenol from the wash water seems likely to prevent widespread use of the method.

The primary shrinkage of the fabric in phenol can, however, be made permanent by steaming at 102° C. for 10 minutes. By its heating effect,

the steam accentuates the shrinking action of phenol, and the enhanced shrinkage is fixed by the occurrence of setting reactions in the fibres of the contracted fabric. Setting reactions are, however, inhibited by acid, and when a series of phenols of increasing dissociation constant were examined, it was found that the dissociation constant must not exceed 1×10^{-9} at 25° C. if the primary shrinkage is to be fixed in steam. For the same reason, fabrics which are likely to retain acid from previous processes, e.g. chlorination, must be neutralised before the application of phenol and steaming. It seems likely that the main application of the process will be in the production of wool crêpes by steaming fabrics on which a suitable phenol has been printed.

Acknowledgment.—The authors are indebted to the Dyestuffs Division of Imperial Chemical Industries Limited for assistance in this work.

REFERENCES

[1] Herzog and Krahn. *Z. physiol. Chem.*, 1924, **134**, 290.
[2] Rhodes and Markley. *J. Phys. Chem.*, 1921, **25**, 527.
[3] Speakman. *J. Soc. Dyers and Colourists*, 1936, **52**, 335.
[4] Speakman. *Proc. Roy. Soc.*, 1931, **132A**, 167.
[5] Speakman. *J. Soc. Dyers and Colourists*, 1936, **52**, 337.
[6] Siefert. *Bull. Soc. Ind. Mulhouse*, 1899, **69**, 86.
[7] Boyd. *J.C.S.*, 1915, **107**, 1540.
[8] Lunden. *Z. phys. Chem.*, 1910, **70**, 249.
[9] Mizutani. *Ibid.*, 1926, **118**, 318, 327.
[10] Murray and Gordon. *J.A.C.S.*, 1935, **57**, 110.
[11] Tiessens. *Rec. Trav. Chim.*, 1939, **48**, 1068.

Textile Chemistry Laboratory,
Leeds University.

(*Received* 28/2/44)

8—A METHOD OF MEASURING THE IRREGULARITY OF CARDED WEB

A. VARGA and N. H. CHAMBERLAIN

INTRODUCTION

During the course of an investigation dealing primarily with the mechanism of the carding process, it became necessary to devise a method for estimating the regularity of distribution of the constituent fibres in the carded web. Any such method involves two separate problems; first, the removal of a representative sample of the web from the card cylinder in such a manner as to preserve faithfully the fibre distribution originally present, and second, the actual estimation of the regularity of such a sample. For the latter purpose, the photoelectric photometer recently described by one of the authors[1] has been utilised in a simple and straightforward manner. The real novelty of the present method lies in the method used for obtaining and preserving the web samples, which will now be described.

Sampling Procedure

It was early realised that any attempt to remove the web from the card cylinder unsupported was unlikely to succeed. The web stripped from the final doffer by the stripping comb is such a tenuous structure that even the most delicate manipulation is likely to introduce irregularities not present in the web on the doffer. Further, there was some evidence that the action of the stripping comb itself might modify the regularity of the stripped web. Accordingly, it was decided to fix the fibres in the positions occupied by them when actually on the wires of the card cylinder by applying to the latter a sheet or strip of transparent adhesive material, to which the fibres could stick, and thus withdraw the web sample attached to the transparent support. This method was found to be simple and reliable in practice. The details were as follows:—

The supporting material used was the self-adhesive cellophane tape now available commercially. A width of four inches was found to be suitable for most purposes, and enables samples to be taken either across the cylinder (i.e., parallel to the axis of rotation) or along the circumference, as circumstances may demand. This tape was found to be very uniform, both in thickness and transparency. A length of this material is laid on the surface of the cylinder and held in position by one operator, while a second presses it firmly on to the wires by means of a rubber roller squeegee such as is used for photographic purposes. Alternatively, the strip may be held in a wooden frame curved to fit the surface of the cylinder, which may be steadied with one hand while the roller is applied with the other. In either event, after thoroughly rolling the tape down, it is carefully lifted from the cylinder, working from the backs of the card wires towards the front, i.e., in the direction in which the wires point. In the case of the doffer, from which samples are most generally taken, the web lies almost entirely on the tips of the teeth and is easily lifted clear. When samples are taken from the swifts or workers, it is sometimes advantageous to slip a piece of thin sheet metal with a smooth edge along under the tape as it is lifted from the cylinder, in order to assist in clearing a small proportion of fibres which are entangled in the lower parts of the card wires. It is found that under these conditions the sample obtained is substantially the "working" web, the "fettling" layer remaining practically undisturbed. Having thus removed

the sample from the card cylinder, a second strip of tape can be placed over it, sticky side down, so that the fibres are sandwiched between the two supports and a permanent preparation is obtained. Air bubbles between the strips are readily avoided, since the fibres provide many capillary channels leading to the edge, along which trapped air can escape.

Measurement of Regularity

The measurement of regularity of fibre distribution in samples so prepared is a comparatively simple matter. A fixed slit is set up in front of the photoelectric cell of the photometer (*loc. cit.*) and the web sample, additionally mounted between two strips of glass of suitable size, is traversed behind the slit, in a direction at right angles to the optical axis of the photometer, by known amounts. The output reading of the photometer is linearly related to the transparency of the portion of web immediately behind the slit; and is hence inversely proportional to its opacity or density. The size of slit used is governed by the type of irregularity which is being investigated. Thus, if a gradual increase in density from, say, one edge of the card to the other, due possibly to faulty feeding, is being sought, a sample taken across the machine and investigated with a wide slit, perhaps 0·5 in., readings being taken every 2 in. along the sample, will suffice; whereas if short-period irregularities are in question, a narrow slit, say, 0·1 in., and correspondingly closer readings will be employed. As regards length of slit, the limit is set only by the complications which the operator is willing to introduce into the optical system of the photometer. The photocell cathode is approximately 1·5 in. long, so that if the slit is illuminated with a parallel beam, a slit length up to this figure can be accommodated without auxiliary optical gear. In practice, a length of 1·0 in. has been found satisfactory for most purposes. No difficulty is found in measuring either thick or thin webs, the sensitivity of the instrument being such that even carded slivers can be measured, though the validity of the results obtained in such a case may be doubtful. No attempt has been made to measure actual average density of a web, say in grams of fibre per square foot, in this manner; such a value, if required, is much more reliably obtained by other methods. The aim has been to measure the variations in density around the mean, and for this purpose it is convenient to set the photometer sensitivity so that the average output reading is approximately the same in all cases. This facilitates visual comparison of the regularity curves, and makes a quantitative estimation of regularity possible. The Coefficient of Variation,

$$\left(\frac{\text{Standard deviation}}{\text{Mean}} \times 100\right)$$

gives such an estimate, providing it is calculated for sets of readings whose means are not widely different. Such sets are obtained by the above technique.

Experimental Results

Figures 1, 2 and 3 show the regularity curves obtained for three web samples, regular, moderately regular, and irregular, respectively. In each case the slit used was 0·1 in. in width and 1·0 in. long, and the sample was moved 0·1 in. between each reading, 90 readings being taken over a 9 in. length of the sample, and the whole of the sample covered by a strip 9 in. × 1 in. surveyed. In each case this actual strip has been photographed above the corresponding regularity curve, the latter being plotted so that each point on the horizontal axis corresponds to the point in the actual sample which lies vertically above it. The correspondence between the density of the actual sample and the ordinates of the regularity curve is apparent in all cases. In particular, the steady decrease in density from left to right in Fig. 1, which is just apparent in the actual sample, is rendered quite evident in the density curve, by a steady fall in average density.

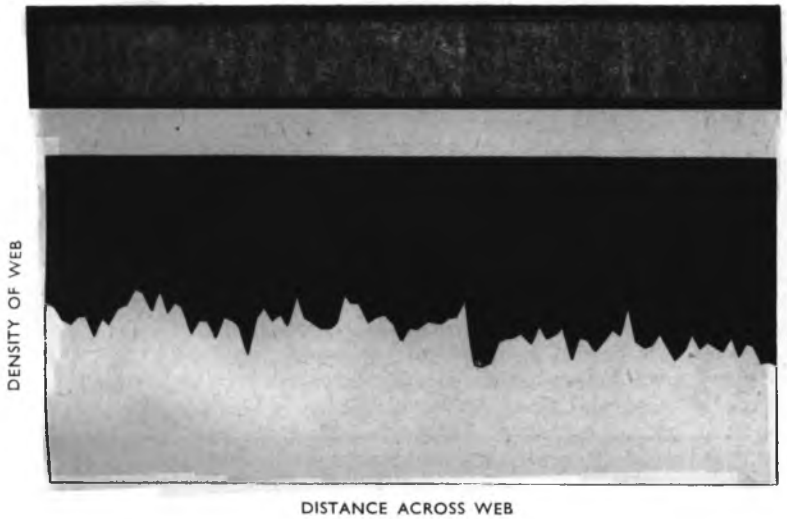
DENSITY OF WEB
DISTANCE ACROSS WEB

Fig. 1

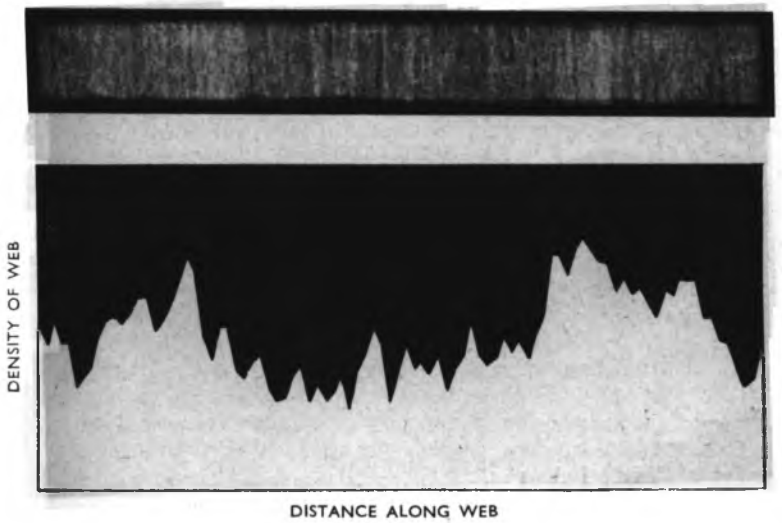
DENSITY OF WEB
DISTANCE ALONG WEB

Fig. 2

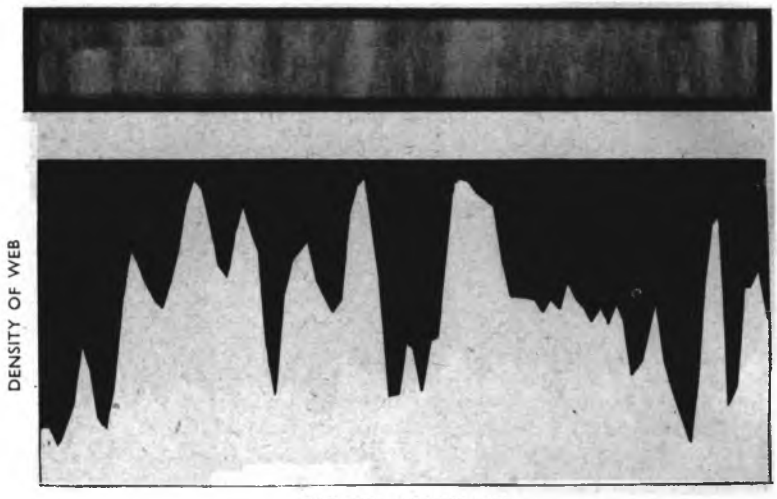

Fig. 3

The standard deviations and coefficients of variation from these curves are given in Table I.

Table I

Web sample	Mean (arbitrary units)	Standard deviation	Coefficient of variation
Regular (Fig. 1)	10·38	1·47	14·20%
Mod. Regular (Fig. 2) ...	9·95	2·60	26·1%
Irregular (Fig. 3) ...	8·79	4·38	49·8%

SUMMARY

A method for removing and preserving samples of web from the carding engine, and estimating the regularity of fibre distribution in such samples photoelectrically, is described.

REFERENCES

[1] Chamberlain. *J. Text. Inst.*, 1944, **35**, T61.

Department of Textile Industries,
Leeds University.

Received 4/3/44