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EFFECT OF pH, TEMPERATURE AND SALT CONCENTRATION ON THE FELTABILITY OF WOOL

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Abstract. It has been shown that while the feltability of loose wool broadly increases with increasing acidity, i.e. decreases with increasing alkalinity up to pH 9-10, there is a peculiar increase around pH 7, followed by a definite decrease and then again a conspicuous increase beyond pH 10. Different quantities of NaCl dissolved in the felting medium accelerate the felting at pH 1.2, but reduce it at pH 5.6 and pH 9.2 under similar conditions. The effect of change of temperature of the felting liquor from 30 to 100°C on the degree of felting has also been investigated at different pH values.

The effect of pH of the felting medium on the degree and rate of felting has been studied in the case of loose wool,[1] wool tops,[2] yarns,[3] fabrics[4–8] and also in the production of felts.[9] The results, though not in complete agreement, show a marked increase in the extent or rate of felting at lower pH and a conspicuous decrease with increase of pH. McPhee and Feldtman[7] observed, for instance, a fall in the initial rate of felting of untreated wool continuously from pH 1.5 to 10. The effect of pH on the feltability of shrink-proofed wools also followed the same pattern, i.e. higher felting at lower pH, and vice versa.

Several conflicting reports[4,10,11] about the effect of temperature and salt concentration of the felting medium are encountered in the literature. Faure[11] observed very anomalous results when he investigated the influence of the concentration of buffer solutions on the feltability at pH 4.6, 7.0, and 9.2, using three wool tops, made shrink-resistant by chlorination treatment at different levels. With untreated top, the feltability increased slightly with increasing concentration of the buffer at pH 4.6, but increased rapidly at pH 7.0 and 9.2. With mildly treated top, increasing feltability was observed at pH 4.6; the effect decreased at pH 7.0, and finally vanished at pH 9.2. In the case of heavily treated top, the feltability first showed a decrease, reached a minimum, and then increased with increase in the buffer concentration at all pH values.

Similiarly, the argument between Speakman[12] and Schofield[13] about the effect of temperature on felting led the former to undertake a second and more comprehensive study[14] on the subject. Present investigation outlines the results obtained in the course of felting experiments at various pH values and at different temperatures and salt concentrations of the felting liquor, in order to further elaborate their effect on the feltability of loose wool.

Materials and Methods

A Merino wool in top form, having fibre dia 27. 1μ and fibre length 9.43 cm, with coefficients of variation 25.6% and 36.4% respectively, was employed, except where otherwise mentioned. The felting technique[1] consisted of three-dimensionally shaking 1 g thoroughly randomized wool-fibres for a fixed interval of time in the appropriate felting liquor, the temperature being controlled thermostatically.[15] This treatment results in the formation of a felt-ball, whose diameter is inversely related to the degree of felting.

The felting medium for pH 1 was prepared from 0.1N HCl, that for pH 2–8 from citric acid and disodium hydrogen phosphate that for pH 9 from borax, and that for pH 10–13 from glycine, NaCl and NaOH mixtures.[16] Various freshly prepared concentrations of NaOH were also used, although the pH values could not be determined accurately in this particular case, due to limitations of the glass electrode pH-meter employed for these measurements.

Felting was conducted in 0.5, 1, 2, 3, and 4M NaCl solutions in 0.1N HCl (pH 1.1), distilled water (pH 5.6), but only up to 2M in borax solution (pH 9.2) due to solubility considerations. The felting liquor always had lower pH values after dissolving NaCl, owing probably to change in the conductivity which could have affected the glass electrode measuring system. A similiar fall in pH has already been reported by Faure.[11] Effect of change of temperature on the degree of felting was studied, using felting liquors at pH 1 and 9, and a 0.5% sodium stearate solution (pH 9). This experiment was conducted using Buchi wool (collected from the Bahawalpur District of West Pakistan) after cleansing, randomising by hand cards, and carefully removing all vegetable and extraneous matter as usual.[17] The dimensional attributes of this wool were: mean fibre dia 44.0 μ, coefficient of variation 31.4%, mean fibre length 11.4 cm and coefficient of variation 48.5%.

Results

Tables 1 and 4 give the mean felt-ball dia for Merino and Buchi wools, after shaking 1 g wool in 50 ml liquid for 60 min. Table 2 presents the mean felt-ball diameters (after 30 min shaking time) obtained with different quantities of salt in the felting liquor. The effect of change of temperature of the felting liquor of different pH values on the feltability is summarized in Table 5.

TABLE 1. EFFECT OF pH ON FELTABILITY (MERINO TOP).

pH	Mean felt-ball dia (cm)	
1·1	2·39	
3·1	3·11	
5·2	3·37	
7·2	2·96	
9·2	3·41	
10·0	3·43	
11·0	3·33	
0·05N NaOH	3·17	
0·1N ,,	2·60	
0·2N ,,	2·49	)Wool fibres were visibly damaged
0·3N ,,	2·50	) and extensive yellowing occurred.
0·5N ,,	2·25	)

TABLE 2. EFFECT OF SALT CONCENTRATION ON FELTING (MERINO TOP).

Salt concn	Mean felt-ball dia (cm)		
	pH 1·1	pH 5·6	pH 9·2
Nil	2·58	3·58	3·74
0·5M	2·66	2·91	3·20
1M	2·69	3·03	3·01
2M	2·80	3·00	2·99
3M	2·94	3·04	—
4M	3·31	3·12	—

TABLE 3. EFFECT OF SOAKING TIME ON FELTING (MERINO TOP).

Felting liquor	Mean felt-ball dia (cm)	
	Immediate felting	After soaking for 24 hr
pH 9·2	3·41	3·88
pH 10·0	3·43	3·76
pH 11·0	3·33	3·81
0·1N NaOH	2·60	3·57
0·5N ,,	2·25	Severe degradation dissolution; no ball formation

TABLE 4. FELT-BALL DIA AT DIFFERENT pH VALUES (BUCHI WOOL).

pH(±0·1)	Mean felt-ball dia (cm)	pH (±0·1)	Mean felt-ball dia (cm)
1	2·45	8	2·54
2	2·52	9	2·89
3	2·54	10	2·78
4	2·61	11	2·57
5	2·65	12	2·54
6	2·65	13	2·48
7	2·56		

Discussion

Feltability at Various pH from 1 to 13. The results regarding the effect of pH on feltability (Fig. 1a) are in general agreement with other reports,[2,3,4,7] i.e. better felting at lower pH, except that a minimum felt-ball diameter (better felting) was also observed at pH 7.2 and the maximum feltability on the alkaline side shifted beyond pH 11. This is contrary to the

TABLE 5. EFFECT OF TEMPERATURE ON FELTING (BUCHI WOOL).

Temp (°C)	0·1N HCl (pH 1)	Felt-ball dia (cm)	
		Borax solution (pH 9)	Soap solution (pH 9)
30	2·45	2·89	2·63
35	—	2·97	2·70
40	2·48	2·90	2·69
45	—	2·89	2·80
50	2·32	3·42	2·79
60	2·23	3·33	3·60
70	2·19	3·33	3·68
80	2·21	3·40	3·56
90	2·20)	Balls not properly	formed
100	2·18)		

results of Speakman and his colleagues who reported a maximum milling shrinkage at pH 10 in one report,[4] in which data were not available from pH 4 to pH 8, and a continuous fall in percentage shrinkage from pH 1 to pH 11 in another research paper.[8] These results of Speakman and his coworkers on fabrics together with those of Bogaty *et al.*[2] on tops have been reported (Fig. 1b).

The existence of a comparatively better felting ability at pH 7 (Fig. 1a) is distinctly evident. No other research workers appears to have noted this although a slight improvement in percentage shrinkage around pH 8 is clearly apparent in the plot of Bogaty *et al.*[2] reproduced in Fig. 1(b). The effect could have been masked in Speakman's investigations[4,8] due to the use of fabrics, where constituent fibres are under considerable manufacturing and structural constraints, and are consequently unable to show up the increase in per cent shrinkage markedly apparent in the present results and fairly evident in those of Bogaty *et al.*[2] around pH 7–8. Present findings are, therefore, not inconsistent with earlier researches. The experiment was, however, repeated employing Buchi wool at smaller pH intervals without changing any other condition of felting already specified for the top. The results are presented in Table 4 as also in the upper graph of Fig. 1(a). The variations in the feltability with change in the pH of the felting medium using Buchi wool are not of the same order as those with Merino top (Fig. 1a), due perhaps to the superior felting ability of the former under almost all conditions. It is, nonetheless, fairly clear that the results generally confirm the above findings, regarding marked decrease in the ball diameter (better felting) at pH 7–8 and continuous increase in feltability beyond pH 9.

The reason for unexpectedly good felting around pH 7 and 8 cannot be readily understood. Of course this result could be the outcome of the modification of either, the ease of extensibility, the power of recovery from strain,[4] of the fibres or changes in directional frictional effect.[3,18,19] These factors apart from 'scaliness' a measure of directional friction and a fundamental prerequisite for felting to occur have been consistently shown[4,8,14] by Speakman and his school of thought to play a major role in reconciling almost all the pH and temperature effects. Although comparatively higher values of scaliness have been

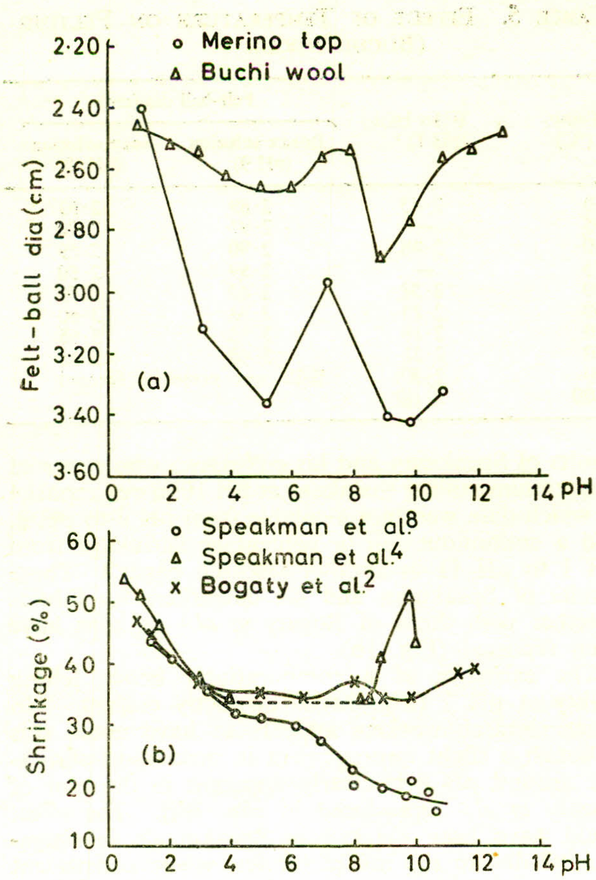

Fig. 1. Relationship between pH and feltability.

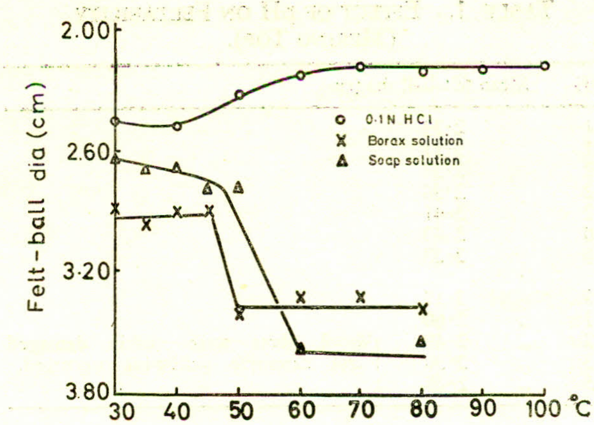

Fig. 2. Effect of temperature on feltability in different felting media.

recorded by the lepidometer method,[8] the particular parameter responsible for the superior felting exhibited at pH 7–8 could not be conclusively determined due to nonavailability of the relevant stress–strain and directional friction data. It is, however, intended to thoroughly reexamine this peculiarity in order to find out a solution consistent with the theories of felting available in the literature.[20]

The continuous increase in feltability on the alkaline side after pH 9 in contrast to a distinctly marked maximum at pH 10 reported by Speakman[4] (Fig. 1b) may be due to the comparative mild conditions of felting and/or use of loose wool instead of fabrics. McPhee and Feldtman[7] failed to come across any maximum on the alkaline side and observed a continuous fall in the initial rate of felting from pH 1.5 to pH 10 using untreated and shrink-proofed fabrics. This result is also at variance not only with the present findings but also with those of Speakman due perhaps to reasons mentioned above. Under severe conditions of felting fabrics, the restrained fibres on account of processing and weaving, as mentioned earlier, are likely to be damaged at higher pH, thus inhibiting fibre migration. Soaking of wool fibres in NaOH solution of various concentrations for 24 hr at room temperature (22–23°C), definitely retarded felting and the ball formation ceased as shown in Table 3. These results support the contention that severe/permanent fibre degradation could be the cause of poorer felting after exhibiting a maximum at pH 10 in the case of Speakman *et al.*[4] and continuous decrease in the initial rate of felting from pH 1.5 to 10 reported by McPhee and Feldtman.[7] The felting technique of the latter workers appears to be extra severe excluding any chance of a maximum shrinkage on the alkaline side.

Effect of Salt Concentration on Feltability. It is apparent (Table 2) that felting is inhibited with increasing quantities of NaCl at pH 1.1 in accordance with Leveau *et al.*[10] but is enhanced at pH 4.6 and 9.2. The results at the two latter values support Faure[11] who observed similar effects with increasing concentration of the buffer solution at pH 4.6 and 9.2 with loose wool felting but are contrary, to Leveau *et al.*[10] who noted a decrease in felting at pH 10.0 which could, perhaps, arise due to the difference in pH.

On the other hand, the decrease in feltability at pH 1.2 (Table 2) follows Leveau and his coworkers[10] but is in contradiction to Speakman *et al.*[4] who found an increase in milling with addition of NaCl in dilute HCl solution. The amount of salt added was, however, not mentioned by the latter and, therefore, a direct comparison is not possible. Further, Faure[11] did not include 0.1N HCl in his experiments, which makes comparisons more difficult. The contradictory results could easily have been caused by different methods of felting and the use of loose wool by Faure[11] and the present author instead of woven[4] and knitted fabrics.[10]

Effect of Temperature on Feltability. Effect of change of temperature from 30°C to 100°C on the feltability using the most disputed felting liquors[4,12,13] is presented in Table 5 and Fig. 2. With increasing temperature, feltability in 0.1N HCl increases from 30°C to 70°C and the ball diameter remains virtually constant after that up to 100°C. As against this, maximum felting, occurs both in borax and soap solutions below 50°C. The feltability in the latter cases decreases sharply after 45 and 50°C respectively as indicated by the increase in ball size (Table 5) and then remains almost constant (Fig. 2). Balls did not form properly at 90 and 100°C in borax and soap solutions implying poor feltability in alkaline media at these temperatures. The wool fibres appeared to glue and fuse together rather than interwine as in other cases. The ball structure was extremely delicate and perishable due, perhaps to possible damage as a consequence of high temperature and pH. The results are in complete agreement with earlier reports [6,13,15] and the occurrence of maximum felting with change of temperature depends upon the pH of the solution.

Since setting up of optimum conditions of maximum and minimum feltability with regard to salt concentration, temperature and pH of the felting liquor, apart from other felting conditions, can certainly help felting and laundering industries, it will not be out of place to encourage extensive studies on these lines employing different salts and a variety of fibre assemblies.

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