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Continuous Dyeing Using Radio Frequency Energy

Part I — Preliminary Trials on Wool

by

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PART I — PRELIMINARY TRIALS ON WOOL

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ABSTRACT

The continuous dyeing of wool tops using a ®Fastran radio frequency (RF) dyeing machine was investigated. The fixation of various reactive dyes onto wool and the processing performance of the wool after dyeing were evaluated and compared with that of wool dyed by conventional exhaust dyeing techniques.

The degree of fixation of various reactive dyes applied in the Fastran RF dyeing machine was very good and very little dye could be rinsed off the fibres after RF dyeing. The fastness to soaping and the degree of covalent fixation of the dyes applied in the RF dyeing machine were generally similar to that of the dyes applied by conventional exhaust dyeing. The degree of levelness of the RF dyed tops was also satisfactory and very good dye penetration was obtained.

In some further studies the processing performance of wools differing widely in diameter and compressibility were evaluated after dyeing. In general, the withdrawal force of the wool tops after RF dyeing was found to be significantly lower than that obtained after conventional dyeing. While the percentage noil during re-combing and the bundle breaking strength of the wool dyed by the RF and conventional techniques appeared to be similar, the RF dyed wool had a slightly lower spinning performance (as determined by the mean spindle speed at break technique) than the wool dyed conventionally.

INTRODUCTION

New techniques and processes are continuously being introduced into the textile industry. One of the more recent developments is the application of radio frequency heat energy for the drying of textiles and the fixation of dyes[1-4]. Radio frequency heating can be divided into two categories.

(a) dielectric heating (frequency 10-100 MHz), and
(b) microwave heating (frequency 900-3000 MHz).

Dielectric heating involves the use of a lower frequency with as high a field strength as possible, without electrical breakdown of the field. Microwave heating, on the other hand, requires a much higher frequency and a comparatively low field strength. Both the dielectric and microwave heating frequencies are in the same region as those used by radio, radar and telecommunication networks[5] and in practice radio frequency heating equipment must operate in narrow frequency ranges outside these networks. Dielectric heating systems generally operate at a frequency of either 13,56 or 27,12 MHz and microwave systems at frequencies of 915 or 2 450 MHz.

Materials that absorb radio frequency radiation are described as 'lossy'[6]. The most important example of a 'lossy' material is water. In a lossy material, the overall molecular structure can be induced to resonate at frequencies similar to the frequency of the radio frequency radiation, resulting in a dielectric loss of the input energy which is converted into heat within the material. The mechanism of heating is related to the polarisation properties of the molecules which absorb the radiation.

In the presence of a high frequency electromagnetic field, the molecules oscillate synchronously with the field at an amplitude that depends on the specific molecule. This molecular oscillation causes heat to be generated by intermolecular friction or agitation induced by rapid reversals of the polarity of the electric field. As long as the absorbing molecules are evenly distributed in the heating zone, the heating effect is completely uniform and does not involve a conducting mechanism such as in steaming where heat is applied from outside the substrate. Most textile fibres on the other hand, are not regarded as 'lossy'[7] and being 'non-lossy' require to be moistened with water, a 'lossy' substance.

Radio frequency heating has been used for many years to provide rapid and efficient heating in a wide variety of applications ranging from the vulcanising of rubber to the cooking of food. In the textile field it has been used mainly for bale heating (softening)[8], drying[9-12] as well as for transfer printing processes[13-15]. More recently, radio frequency heating has been introduced as a means of obtaining rapid fixation of dyes onto textiles. It has been claimed that this mode of heating produces level dyeings and a high degree of dyestuff fixation[16]. It appears that the dielectric type of equipment finds more general application in the textile industry and involves less capital cost than microwave equipment[5]. Furthermore, radiation energy in the frequency range 10-100 MHz is regarded to be more controllable and less harmful than microwave radiation (900-3000 MHz). (International standards specify a maximum or ultimate stray radiation of 10 milliwatts per square centimetre of exposed body surface.)

In view of the potential advantages of dielectric heating techniques in general, and the use of these techniques for dye fixation in particular, it was decided to study the dielectric dyeing of wool in more detail.

There are two different approaches to the radio frequency dyeing of fibres such as wool, namely the ®Lanapad and the ®Fastran processes. The Lanapad process is a semi-continuous dyeing method in which the wool is padded with a dye solution, heated to about 60°C by means of radio frequency energy and stored overnight in insulated containers to maintain the temperature, before washing-off. The Fastran process, on the other hand, is a continuous method in which the wool is padded with dye, followed by radio frequency heating which produces immediate fixation of the dye and a final wash-off, the latter taking place in a separate process. Since a fair amount of information is already available on the dyeing of wool according to the Lanapad process[17], while relatively little is known about the Fastran dyeing process, it was decided to investigate the continuous dyeing of wool using the Fastran machine.

A general view and a schematic diagram of the Fastran machine are given in Figures 1 and 2, respectively. The maximum production of this specific machine is 15 kg/hr but machines with a production rate of up to 450 kg/hr are commercially available.

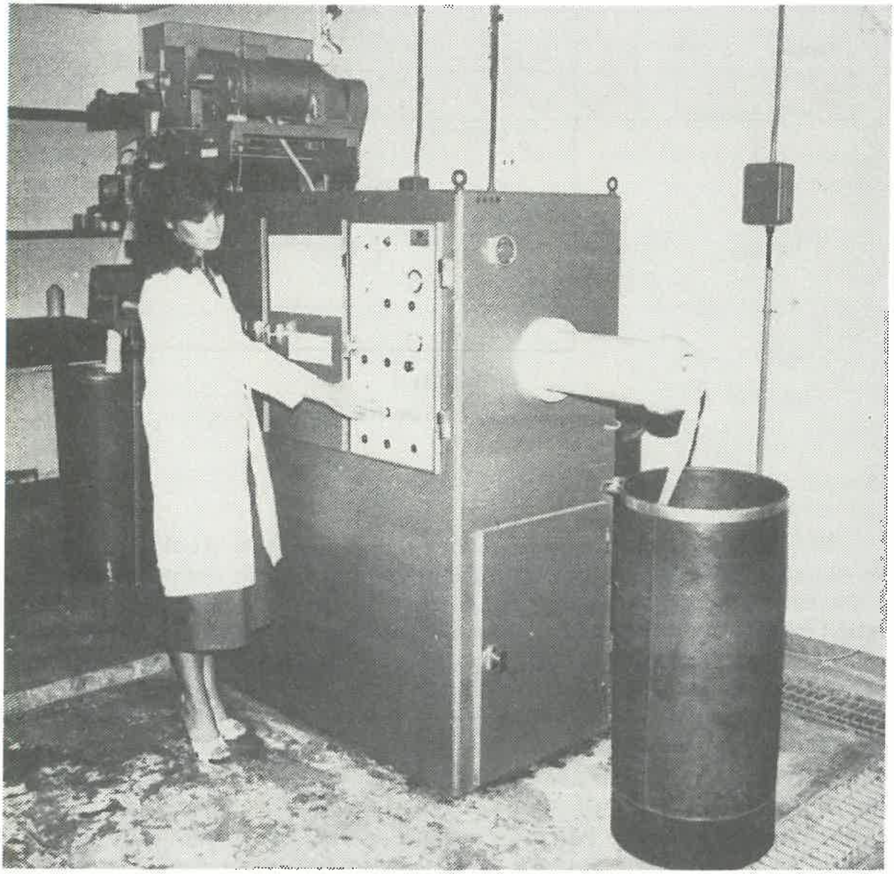

FIGURE 1

A General View of the Fastran Dyeing Machine

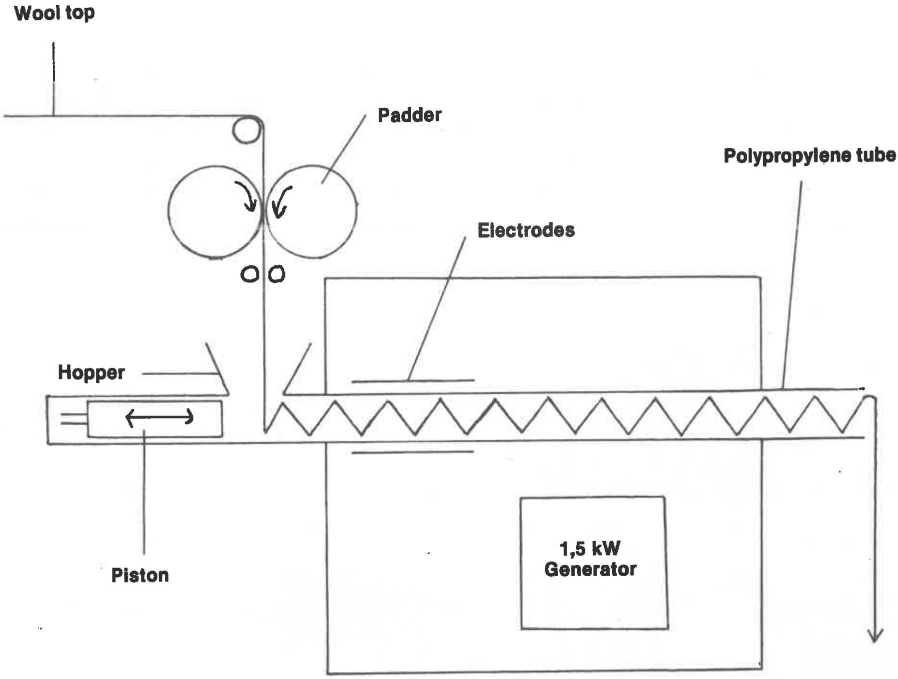

FIGURE 2

A Schematic Diagram of the Fastran Dyeing Machine

The principle of operation is as follows: Undyed wool tops are impregnated with a solution containing dyestuff and various dyeing auxiliaries in a conventional padding system. The nip pressure of the padding rollers can be varied from 0 to 1000 kPa and the surface speed of the rollers can be varied up to a maximum value of 22 m/min . After padding, the wool is fed into a hopper directly above a piston (ram) feed section which pushes the top into the polypropylene tube or fixation chamber. The piston pressure can be varied from 0 to 1000 kPa while the dwell period of the piston at the end of its forward and backward stroke can be varied between 1 and 10 seconds. Radio frequency (dielectric energy) is used to heat the wool to a temperature slightly higher than 100°C. The Fastran machine operates at a frequency of 27,12 MHz. The wool remains between the electrodes for about 5 minutes with the total time for which it remains in the tube varying from about 20 to 30 minutes, depending on the production rate.

EXPERIMENTAL

Wool:

Wool tops with a linear density of 23 g/m and differing in mean fibre diameter and resistance to compression were used. (Diameter and resistance to compression values will be given in the text.) The average mean fibre length was 55 mm while the average dichloromethane extractable matter content of the wool was 0,7%.

Treatments:

Radio Frequency Dyeing

Wool tops were padded to a 80% wet pick-up with various reactive dyes (see Table I) in a solution containing:

20 g/ℓ	Dye
1,5 g/ℓ	Acetic Acid
20 g/ℓ	®Levalin VKU (a coacervate)
0,5 g/ℓ	®Albegal FFD (an anti-foam)
10 g/ℓ	Ammonium Sulphate
20 g/ℓ	®Solvitose C5 Thickener.

The energy (E) required to fix the dye was calculated according to the following formula as supplied by the manufacturers of the machine:

$$E = (C \times P \times H \times T) + (C \times M \times H_1 \times T) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where C = a constant (69,7)
P = production rate (kg/hr)
H = specific heat of wool (taken as 0,3)
H_1 = specific heat of water (taken as 1)
M = moisture pick-up of wool (kg of water/kg of dry wool)
T = temperature rise (°C — from 20°C to 104°C).

The surface speed of the padding rollers was set at 7 m/min; the nip pressure gauge was set at 325 kPa to give a wet pick-up of 80%; the piston pressure gauge was set at 400 kPa while the piston dwell period was set at 7 and 4 seconds at its forward and backward stroke, respectively. Under these conditions of treatment, the power required to fix the dye was calculated, using equation (1), to be 1,04 kW/hr and the machine was accordingly set at 400 mA to produce this amount of energy.

Conventional Exhaust Dyeing

Laboratory scale dyeings were carried out on an Ahiba Turbomat dyeing apparatus and bulk dyeings on a Vald. Hendriksen Dyeing machine using 1,8% dye (on mass of wool). The dyeings were performed according to the recommendations of the manufacturers of the dyestuffs.

Backwashing:

Both the radio frequency and conventionally dyed wool tops were backwashed after dyeing using 0,05% ®Berol Lanco at 50°C, followed by rinsing at 50°C and drying at 100°C.

Test Methods

The amount of unfixed dye which was loosely associated with the wool and which could be extracted with cold water, the amount of dye remaining on the fibres after soaping with ®Ultravon HD for 20 minutes at 100°C and the degree of covalent fixation of the dye (determined by extraction with boiling 20% (v/v) pyridine) were determined spectrophotometrically on tops which had not been backwashed after dyeing. The fastness to washing of the dyed wool was determined according to the ISO 3 test. The percentage noil during re-combing was determined on a Schlumberger PB 26 worsted comb. Spinning performance of the wool was determined by the Mean Spindle Speed at break (MSS) technique[18]. Withdrawal force and bundle breaking strength determinations were performed using the SAWTRI Withdrawal Force and the ®Spinlab Stelometer Bundle Breaking Strength Tester, respectively.

RESULTS AND DISCUSSION

Dye Fixation

In this investigation the continuous dyeing of wool using radio frequency (RF) energy to achieve dye fixation, was evaluated by direct comparison with a conventional exhaust dyeing carried out in an Ahiba dyeing apparatus. Initially, the percentage fixation of various reactive dyes on wool dyed conventionally and by the Fastran RF technique was compared. The results are given in Table I.

Table I shows that very high fixation values were obtained on the wool dyed in the RF machine. It is interesting to note that only a very small amount of dye could be removed from the wool by rinsing in cold water. This dye was probably deposited on the surface of the fibres. On average more than 98% of the dye which had been applied to the wool could not be removed by rinsing in water. This compares favourably with conventional dyeing where an average exhaustion of about 96% was obtained. Furthermore, the RF dyer produced dyeings which showed the same fastness to soaping than that obtained during conventional dyeing. Finally, Table I shows that the degree of covalent fixation of the dyeings produced by the RF machine was similar to that obtained in the conventional exhaust dyeing process.

The degree of levelness of the dyed tops was very good and satisfactory dye penetration was obtained in all cases. The fastness to washing of the dyed wool was also very good and a grey scale rating of 5 was obtained on all the dyed samples with no staining of the adjacent fabrics after an ISO 3 wash test.

TABLE I

PERCENTAGE FIXATION OF VARIOUS REACTIVE DYES ON WOOL TOPS* DYED CONVENTIONALLY AND IN THE FASTRAN DYEING MACHINE

DYE	RF DYEING			CONVENTIONAL DYEING		
	% Dye on Wool		% Covalent fixation	% Exhaustion	% Dye on wool after soaping at 100°C	% Covalent fixation
	After extraction with water	After soaping at 100°C				
®Hostalan Red 4B	98,5	94,4	75,8	98,7	94,7	87,6
®Drimalan Yellow F3-G4	98,3	97,6	91,6	94,2	90,1	72,1
®Lanasol Yellow 4G	98,9	92,0	83,6	94,3	92,9	84,2
®Verofix Orange 3 GL	98,4	93,7	85,8	98,0	96,8	92,2

*Diameter 21,1 μm; Length 54,9 mm

In general, the fixation of dyestuff and the fastness to washing of the wool dyed in the Fastran machine compared favourably with that of wool which was exhaust dyed according to conventional methods and it is likely therefore, that the RF dyed wool would also compare favourably with wool dyed according to the IWS cold pad-batch method or the pad-batch microwave fixation method[19].

Processing Performance

In the Fastran top dyeing machine the wool is compressed considerably by the action of the piston. The compressed wool is then pushed through the tube at a temperature which exceeds 100°C. It is possible therefore that some fibre damage may occur in the dyeing tube. Furthermore, wools differing in their resistance to compression may differ in their dyeing behaviour. It was decided, therefore, to study the dyeing behaviour and processing performance of wools differing in their resistance to compression. Consequently four different wool tops of nominally the same mean fibre diameter (21,7 μm) and length (54,8 mm) but varying in their resistance to compression were dyed with ®Lanasol Yellow 4G according to the procedure described previously. For purposes of comparison, some of the tops were exhaust dyed conventionally in a Vald. Hendriksen Top Dyeing Machine. The dye fixation values are given in Table II while the withdrawal force, combing and spinning performance results are given in Table III.

From Table II it can be seen that there was little difference between the fixation values of this particular dye when dyed in the RF machine and when dyed conventionally. In the case of RF dyeing, there seemed to be a slight decrease in the percentage covalent fixation with an increase in the resistance to compression of the wool.

In order to evaluate the processing performance of these wools, a multiple regression analysis was carried out on the results in Table III.

From Table III it is clear that the withdrawal force of the wool was significantly increased by the dyeing treatments. The statistical analysis indicated, however, that the increase in the withdrawal force was not dependent on the resistance to compression of the wool but was only a function of the dyeing method. Wool dyed in the RF machine showed a significantly lower withdrawal force than wool dyed by the conventional technique. These differences were most likely the result of differences in the degree of entanglement of the fibres although differences in fibre friction could also have played a rôle. A visual inspection of the two tops clearly showed that the RF dyed wool was less entangled than the conventionally dyed tops.

An increase in the fibre entanglement was expected to influence the processing performance of the wool. Table III shows that dyeing in general increased the percentage noil slightly. The statistical analysis of the results indicated, however, that no significant differences existed between the recombing performance of the RF and conventionally dyed wool. Furthermore, the variations in the resistance to compression of the wool had no effect on the results. The spinning performance (as determined by the MSS technique) of the untreated and conventionally dyed wool was the same and was not dependent on the resistance to compression of the wool. The MSS values of the wool

TABLE II

THE EFFECT OF RF AND CONVENTIONAL EXHAUST DYEING ON THE FIXATION VALUES OF WOOLS DIFFERING IN THEIR RESISTANCE TO COMPRESSION

Compressed Height of Steamed Top (mm)	RF DYEING			CONVENTIONAL DYEING		
	% Dye on Wool		% Covalent fixation	% Exhaustion	% Dye on wool after soaping at 100°C	% Covalent fixation
	After extraction with water	After soaping at 100°C				
15,0	99,3	95,3	81,6	96,5	96,1	85,0
16,8	99,1	94,1	79,1	96,5	95,9	74,6
19,6	99,0	94,7	75,1	96,5	95,2	78,8
23,2	98,7	93,4	72,9	96,5	95,7	79,6

TABLE III

THE EFFECT OF RF AND EXHAUST DYEING ON THE PROCESSING PERFORMANCE OF WOOLS DIFFERING IN THEIR RESISTANCE TO COMPRESSION

Compressed Height of Steamed Top (mm)	Mean Fibre Diameter (μm)	Withdrawal Force After Backwashing (N/g)			% Noil			Spinning Performance: Mean Spindle Speed at break (rev/min)		
		Untreated Control	Conventional Dyed	RF Dyed	Untreated Control	Conventional Dyed	RF Dyed	Untreated Control	Conventional Dyed	RF Dyed
15,0	21,3	102,9	312,6	221,5	0,5	0,8	0,7	13 361	12 972	11 756
16,8	21,8	107,8	266,6	229,3	0,6	0,7	0,5	11 944	12 138	11 228
19,6	21,9	82,3	284,2	172,5	0,6	0,8	0,8	11 423	11 784	11 597
23,2	21,9	101,9	287,1	187,2	0,7	0,8	0,9	12 312	12 395	11 332

dyed in the Fastran machine, however, were on average about 5% lower than those of wool dyed in the conventional manner. Furthermore, the statistical analysis showed that the MSS values of the RF dyed wool were dependent on the resistance to compression of the wool and decreased slightly when the resistance to compression increased. This decrease, however, is marginal and it can be assumed that dyeing of wool tops having different resistance to compression values in the RF dyer should not influence the processing performance of the tops to any extent.

Wool differing widely in mean fibre diameter but having similar resistance to compression values were also dyed according to the RF and conventional dyeing techniques. The processing performance results of the undyed and dyed tops are given in Table IV. A multiple regression analysis was carried out on these results.

The analysis showed that the withdrawal force of the dyed wool was independent of the mean fibre diameter of the wool. It was dependent, however, on the dyeing method used, as was the case previously with the wools having the same diameter but differing in resistance to compression. Conventional dyeing resulted in tops with a significantly higher withdrawal force than RF dyeing. The percentage noil produced during re-combing of the wool dyed by the conventional and RF techniques was similar and depended only on the diameter of the wool. The percentage noil decreased when the mean fibre diameter of the wool increased.

RF dyeing once again seemed to influence the spinning performance of the wool. Although the MSS values of the wool dyed according to the RF technique were independent of the mean fibre diameter (the yarns were spun to the same average number of fibres in their cross-section), RF dyeing gave slightly lower MSS values than the untreated control or the conventionally dyed wool. There are various possible reasons for this phenomenon. Amongst others, this might have been due to differences in bundle tenacity of the fibres. A statistical analysis of the results, however, showed that the RF and conventionally dyed wool had similar bundle-breaking strength values. The effect of the different dyeing treatments on the frictional properties of the fibres are at present being studied and will be reported on at a later stage.

SUMMARY AND CONCLUSIONS

A study has been undertaken to investigate the use of radio frequency energy for the fixation of dyes on wool using a Fastran continuous top dyeing machine. The fixation of various types of reactive dyes as well as the processing performance of the wool was evaluated by a direct comparison with wool tops which were exhaust dyed in a conventional manner.

TABLE IV

PROCESSING PERFORMANCE OF WOOL WITH DIFFERENT MEAN FIBRE DIAMETER VALUES AND DYED ACCORDING TO RF AND CONVENTIONAL TECHNIQUES

Mean Fibre Diameter (µm)	Withdrawal Force After Backwashing (N/g)			% Noil			Spinning Performance: Mean Spindle Speed at break (rev/min)			Bundle Breaking Strength (cN/tex)					
										Untreated Control		Conventional Dyed		RF Dyed	
	Untreated Control	Conventional Dyed	RF Dyed	Untreated Control	Conventional Dyed	RF Dyed	Untreated Control	Conventional Dyed	RF Dyed	After Back-wash	After Comb-ing	After Back-wash	After Comb-ing	After Back-wash	After Comb-ing
19,6	40,8	293,7	313,5	0,7	0,9	1,1	12 485	12 221	11 110	12,3	11,7	11,4	11,5	10,9	11,4
23,8	54,7	570,9	273,2	0,4	0,5	0,5	12 374	12 291	12 194	12,3	10,0	11,6	11,4	11,2	11,1
29,3	17,6	267,2	174,1	0,3	0,4	0,4	12 194	11 694	11 388	11,3	13,1	14,2	13,2	12,9	12,7

Initially, four different types of reactive dyes, together with the prescribed auxiliaries, were padded onto the tops which were then passed through the RF dyeing machine. The fixation values of the different dyes after RF dyeing compared favourably with those obtained by conventional exhaust dyeing. Very little of the dye could be removed from the RF dyed wool by rinsing in water. Furthermore, the RF dyed wool had the same fastness to soaping at 100°C as that found for the conventionally dyed wool. It was also found that the degree of covalent fixation of the dyes treated in the RF dyer was the same as that obtained during the conventional dyeings. The degree of levelness of the dyed tops as well as the fastness to washing of all the dyeings (ISO 3) was very good.

During the dyeing of wool in the Fastran machine, the tops are compressed considerably in the RF dyeing tube and it was considered important to establish whether this compression of the tops would have an adverse effect on the strength and the processing performance of the wool. Wools differing in their resistance to compression were therefore dyed in the RF dyer and according to a conventional exhaust dyeing technique. Little difference was found between the fixation values of the dye regardless of whether the wool was dyed according to the RF technique or dyed conventionally. There was a slight tendency for the degree of covalent fixation of the wool dyed in the RF machine to decrease with an increase in the resistance to compression of the wool. Resistance to compression had no effect on the degree of covalent fixation in the case of the wool which was dyed conventionally.

Both dyeing techniques resulted in a significant increase in the withdrawal force of the fibres. The RF dyeing technique, however, produced wool tops exhibiting a considerably lower withdrawal force than did the conventional dyeing process. Furthermore, a visual inspection of the two tops clearly showed that the RF dyed wool was less entangled than the conventionally dyed tops. Despite these differences, however, no difference was found between the percentage noil produced during the re-combing of the wool dyed according to RF or conventional techniques.

The spinning performance (MSS test) of RF dyed wool was, however, slightly lower than that of the conventionally dyed wool. While the MSS values of the untreated and conventionally dyed wool were independent of the resistance to compression of the wool, the MSS value of the RF dyed wool decreased marginally when the resistance to compression of the wool increased.

Finally, wools with different mean fibre diameters, ranging from 19,6 μm to 29,3 μm, but having the same resistance to compression were dyed and tested as before. Once again it was found that the RF dyeing technique resulted in tops with a lower withdrawal force than the conventional dyeing process. Both dyeing techniques produced tops giving similar percentages noil during recombing, as well as similar bundle breaking strength values. The spinning performance of the RF dyed wool was, however, slightly lower than that of conventionally dyed wool. The reasons for this behaviour are not yet quite clear, but may be the result of changes in the fibre-to-fibre friction and cohesion as a result of some residual thickening agent, and some more work will be carried out on this matter in the future.

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