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Part II: A Preliminary Assessment of Potential Energy Saving

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CONTINUOUS DYEING USING RADIO FREQUENCY ENERGY

PART II: A PRELIMINARY ASSESSMENT OF POTENTIAL ENERGY SAVING

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ABSTRACT

Preliminary dyeing trials were carried out on various synthetic fibres and wool using radio frequency (RF) energy for dye fixation. The fibres were dyed continuously in tow or loose stock form using conventional dye formulations. Level dyeings were obtained in all cases. In the case of acrylic and nylon fibres, dyestuff fixation was very high, while the wash- and lightfastness ratings of the dyed fibres were similar to those of fibres dyed by conventional techniques. Good fixation of dye was obtained when polyester was dyed with low concentrations of dye. An increase in the concentration of dye, however, resulted in a reduction in the dye fixation, probably due to the fact that the dyeing temperature was somewhat lower than that used for conventional polyester dyeings.

An assessment of the potential saving in energy using the radio frequency dyeing technique was also made. It was found that the radio frequency dyeing process resulted in a saving of about 80% in dyeing energy costs, when compared with conventional aqueous dyeing. A break- even cost analysis, indicated an added advantage of 4,0 c/kg fibre for the RF dyeing process.

INTRODUCTION

The present energy situation in the world has forced governments and industrialists to take drastic steps to conserve fuel and other sources of energy. Compared to other industries, the textile industry is a relatively small consumer of energy and it normally ranks below industries such as chemicals, metals, paper, food and machinery[1]. In practice, however, textile mills are still consuming large amounts of energy and economic conditions necessitate the introduction of various measures to conserve fuel. A breakdown of the energy consumption of textile mills shows that wet processing (preparation, dyeing and finishing) generally requires the largest amount of energy. Wet processing can use from 40% to 80% of the total amount of energy required to produce a textile product from the raw fibre[2]. It is not always possible to give an accurate breakdown of dyehouse cost, but it is generally accepted that the energy cost amounts to about 10—15% of the total dyehouse cost[3-4]. It is obvious therefore, that any saving in dyehouse energy cost would have a beneficial effect on the profitability of the mill.

There are various possible ways in which energy can be saved in the dyehouse. For example, the efficiencies of all equipment using energy can be improved through various means. This approach has certain limitations, however, and in order to save more energy, attention has to be paid to new developments in this field. One such development, which is becoming increasingly more important in the textile industry, is the use of radio frequency heating. It is claimed that overall efficiencies, i.e. conversion of mains electricity to heat energy in the material being treated, of more than 70% can be obtained for the heating of textile materials[5]. With conventional steam heating, on the other hand, the efficiency drops to around 40% at the point of application.

By virtue of the mechanism by which substances are heated by radio frequency energy, heat is generated *within* the material. In all other forms of heating, on the other hand, the heat is applied from outside the substrate and it can only reach the inside by some heat transfer mechanism, such as convection, conduction or radiation. Textile fibres by nature, are poor conductors of heat and radio frequency energy therefore has the advantage of resulting in rapid, uniform and controlled heating. Furthermore, radio frequency energy has the advantage that heaters can be designed in such a manner that the energy is directed towards the material, thus eliminating unnecessary heat losses. In contrast to other methods of heating, start up and shut down are almost instantaneous, thus avoiding lengthy pre-warming or cooling stages.

Although technically very attractive, the application of radio frequency energy for heat treatment of textiles was considered initially not to have any economical advantages[6]. With the increase in energy cost, however, radio frequency drying has become economically viable and in recent years several publications have reported on the cost benefits of radio frequency energy. For example, it was reported that a reduction of over 60% in the cost of drying textile fibres after dyeing was obtained through the installation of a radio frequency dryer[7]. Apart from drying, radio frequency energy can also be used for dye fixation[8-10]. This is a very recent development and relatively little is known about the energy requirements of such a process. It was considered important, therefore, to assess the potential savings in energy which could be realised when radio frequency dyeing techniques are used instead of conventional dyeing processes. A series of experiments therefore was carried out during which various fibres were dyed in a ® FASTRAN RF machine. The power consumption during dyeing was determined and compared with that reported for conventional aqueous dyeing. The study covered polyester, nylon, wool and acrylic fibres. Apart from the energy consumption, the dyestuff fixation and some fastness properties of the dyed fibres were also determined.

EXPERIMENTAL

Materials

Polyester, nylon, acrylic and wool fibres were used in this study. The polyester (Trevira 820, 16,7 dtex, 150 mm) and nylon, (Nylon 6, 8,8 dtex, 150 mm) were used in staple form and the acrylic (Acrilan S16, 5,5 dtex) was used in the form of tow. The wool (21 μm diameter) was used in the form of slivers with a linear density of approximately 20 g/m .

Dyeing

The fibres were dyed in a ®FASTRAN radio frequency (dielectric) continuous top dyeing machine described previously[8]. During radio frequency dyeing the substance to be heated is placed between two electrodes across which a high potential radio frequency voltage is developed. The radio frequency high voltage field is produced by converting the conventional mains AC supply of 220 volts, 50 cycles/sec to a direct anode voltage of 4,5 to 10 kV and then pulsing this supply to whatever frequency is required, for example, 27,12 magahertz.

The dyestuffs and auxiliaries used were of commercial grade quality. The dye formulations used during radio frequency dyeing were similar to those used commercially for conventional dyeing techniques. The temperature during dye fixation was measured by means of temperature strips sealed in polyethylene bags. The energy consumption during dyeing was measured with the aid of a Kilowatt-hour meter connected to the AC supply.

Tests

The washfastness properties of the dyed fibres were determined according to the ISO No 3 test. The lightfastness properties were measured after exposure to a Xenon arc lamp.

RESULTS AND DISCUSSION

Fastness properties of dyed fibres

Batch sizes varying from 10-50 kg of the various fibres were continuously dyed in the FASTRAN dyeing machine. Level dyeings were obtained in all cases. Some of the results obtained during the dyeing of the synthetic fibres (polyester, nylon and acrylic) are given in Table I.

It is clear that the dye fixation was very good when polyester fibres were dyed to a pale shade (Experiment No 1) in the FASTRAN machine. This is reflected in the rinse water and reduction clearing water ratings. The lightfastness and washfastness properties of the dyed polyester were also good.

When the dye concentration was increased to produce deep shades (Experiment No 2), however, a deterioration in dye fixation was observed. In this case there was a significant increase in the amount of dye removed from the fibres during reduction clearing and rinsing treatments. Although an increase in the amount of carrier used during dyeing (Experiment No 3 and 4) improved the dye fixation somewhat it is clear that the fixation was not quite acceptable, even in the case where an excess of carrier was used. The performance of low energy disperse dyes was then evaluated (Experiment No 5 and 6). The results indicate an improvement in the fixation (reduction clearing water rating of 4) but the amount of dye removed during rinsing was still unacceptably high, even when relatively high amounts of carrier were used.

In contrast to the polyester, the dye fixation in the case of the nylon and acrylic fibres was very good. Table I shows that practically no dye was removed during the rinsing of nylon and acrylic fibres. The wash- and lightfastness ratings of the dyed nylon and acrylic fibres were also good and of the same standard as that obtained when the fibres were dyed with these dyes according to conventional techniques.

As yet, only a few specific dyes have been evaluated, but it is clear that by suitable choice of dye formulations, pollution can be reduced or eliminated by the radio frequency dyeing technique. With the exception of the high energy disperse dyes, practically 100% fixation was obtained in all cases.

The dyeing temperature, namely 116°C, is the maximum temperature recorded in the dyeing tube during the course of the dyeing trials and do not necessarily mean that the fibre had been at that particular temperature for the total dyeing period, namely 25 minutes. In practice the dyeing temperature can be varied, by changing the energy output. The maximum dyeing temperature which can be attained at present is approximately 116°C due to the fact that a polypropylene dyeing tube is being used. A special glass tube together with a discharge unit for controlling the packing density of the material inside the tube, which will probably enable dyeing to be carried out at temperatures of up to 125°C is at present being installed. This will enable high temperature dyeing to be carried out in further investigations.

Another interesting observation made during these trials, concerns the presence of oligomers on the dyed polyester fibres. In is well-known that the use of carriers or the dyeing of polyester at high temperatures is normally associated with the formation of oligomers on the fibre surface. Apart from the fact that this causes problems to the dyer, due to a build-up of oligomers in the dyeing machines, the presence of oligomers on the fibre surface also is detrimental to the processing performance of the fibre after dyeing. The present study revealed that the amount of surface trimer formed during radio frequency dyeing was significantly lower than that found during conventional aqueous dyeing of polyester. In fact in all the cases studied, including the trials

TABLE I

DYEING PARAMETERS AND SOME FASTNESS PROPERTIES OF RADIO FREQUENCY DYED SYNTHETIC FIBRES

Experiment No.	Fibre	Dye (C I Numbers)	Dye Conc. (g/kg)	Carrier Conc. g/ℓ	Pick-Up (%)	Light Fastness Rating	ISO 3 TEST: Shade change rating	ISO 3 TEST: Cross stain rating	Rinse Water Rating	Reduction Clearing Water Rating
1	Trevira 820	Disperse Yellow 114 Red 184 Blue 165	0,356	® Viscavin G.R. 0.5	100	6	5	5	5	5
2 3 4	Trevira 820	Disperse Yellow 114 Red 184 Blue 165	30,0	® Invalon TA 1.0 10 100	100	4-5 4-5 4-5	5 5 5	5 5 5	1 2 3	1 2-3 3
5 6	Trevira 820	Disperse Yellow 54 Red 50 Blue 56	9,0	® Invalon TA 1.0 10.0	100	5 5	5 5	5 5	2-3 2-3	4 4
7	Nylon 6	Acid Blue 317 Yellow 177.1 Red 315	12,777		100	6	4	4	5	
8	Acrilan S16	Basic Red 54 Yellow 45 Blue 147	4,845		100	5	5	5	5	

with the very high amounts of carrier, the surface trimer content of the fibres was lower than 0,05%.

Cost Comparison between RF and Aqueous Dyeing Techniques

It is quite clear that RF dyeing, compared with conventional dyeing techniques, offers several technical advantages. An important aspect to be considered with any new technology, however, is whether it will be economically advantageous. It was considered important, therefore, to determine the energy consumption of the RF dyeing process (per kg of fibre dyed) and to carry out a cost comparison between this technique and conventional aqueous dyeing techniques.

Hence, the power consumption during the dyeing trials was determined. From this the dyeing cost (per kg of fibre dyed) was calculated. The results are given in Table II. The average energy costs for the dyeing of textiles by conventional aqueous continuous dyeing processes based on results obtained during a survey conducted at various South African mills, are approximately 4,15 c/kg[11]. It must be pointed out that most aqueous dyeing processes utilise

TABLE II

THE ENERGY CONSUMPTION AND ENERGY COST OF RADIO FREQUENCY DYEING COMPARED WITH CONVENTIONAL DYEING

Fibre	Radio Frequency Dyeing		Conventional Dyeing
	Energy Consumption (kWh/kg)*	Energy Cost (c/kg)	Energy Cost (c/kg)
Wool	0,35	0,774	4,15
Acrylic	0,34	0,751	
Nylon	0,35	0,773	
Polyester	0,28	0,619	

*The 15 kg/hr machine used in this study has been equipped with a relatively large padder which could maintain a production rate of 100 kg/hr, and which thus consumes a relatively high percentage of the total amount of energy. On the larger (100-500 kg/hr) production machines, the energy consumption would be lower than that reported in the Table due to better utilisation of the padder.

steam (for heating) as well as electricity (for driving motors) and that the aqueous dyeing cost therefore is in respect of steam as well as electricity. In the case of radio frequency energy, on the other hand, only electrical power is used. It is clear from Table II that there are significant differences between the

dyeing energy costs of aqueous and radio frequency dyeing. In fact, for all four types of fibres studied, the RF dyeing energy costs was less than one-fifth that of the aqueous dyeing processes. The average percentage saving in energy by using the RF technique is approximately 80%.

TABLE III

COMPARISON OF AQUEOUS AND RADIO FREQUENCY DYEING COSTS

Operation	Aqueous Dyeing (c/kg)	Radio Frequency Dyeing (c/kg)	Savings (c/kg)
Dyeing and Drying*	5,35	1,93	3,42
Labour	9,48	6,64	2,84
Water and Effluent	1,97	1,18	0,79
Total	16,8	9,75	7,05

* It was assumed that the *drying* energy costs were the same for both processes, and a value of 1,2 c/kg was considered to be typical for South African mills.

Dyeing energy costs, however, constitutes only part of the overall cost of dyeing and factors such as labour, drying costs as well as water and effluent costs should also be taken into account[6]. The above parameters were therefore, included in a further cost analyses. Table III gives a comparison of aqueous[11] and radio frequency dyeing costs, taking dyeing and drying energy, labour, water and effluent costs into account. The dye formulations used for RF dyeing were identical to those used for aqueous dyeing and the chemical cost was therefore identical in both cases. There are some indications, however, that the amount of auxiliaries required for RF dyeing can be reduced considerably or even completely omitted from the RF dye formulations, except for a small amount of thickening agent[12]. It was assumed that, in the case of radio frequency dyeing, a saving of 30% in labour and 40% in water and effluent costs could be made. The latter was based on the fact that the liquor to goods ratio during radio frequency dyeing is about 1:1, while it was assumed that the average liquor ratio for conventional exhaust dyeing is approximately 20:1. Table III clearly shows that radio frequency dyeing results in an average saving of 7,05 c/kg fibre dyed. This represents a saving of about 40%, compared with aqueous dyeing costs.

Since the use of radio frequency energy for dye fixation results in considerable savings, it was considered important to establish the overall dyeing cost i.e. inclusive of machine cost, depreciation, etc. This cost analysis was based on the following assumptions:

a) Cost of radio frequency dyeing machine having a production of 500 kg/hr is R600 000.
b) Cost of conventional aqueous dyeing machine is R325 000.
c) Total annual production of both machines is 3 million kilograms of fibre.
d) Selling price of dyed goods from both machines is the same.

A typical situation where a company has to decide between the purchase of a conventional aqueous dyeing plant or a radio frequency dyeing machine is illustrated in Table IV. This Table gives a cost analysis to derive a break-even value allowing for the depreciation over 10 years, a return on capital of 10% for 10 years and a 40% tax rate.

TABLE IV

"BREAK-EVEN" COST ANALYSIS OF CONVENTIONAL AQUEOUS AND RADIO FREQUENCY DYEING PROCESSES

Investments	Dyeing Process	
	Conventional	Radio Frequency
Capital (C)	R 325 000	R 600 000
Value added based on an annual production of 3 million kg fibre	R 504 000	R 292 500
Plus: Depreciation over 10 years and a return on capital of 10% for 10 years (Tax rate 40%)	R 109 800	R 202 700
Break-Even	R 613 800	R 495 200

It is clear that the break-even point for the RF dyeing process is R118 600 lower than that for the conventional dyeing process. This difference represents an added advantage of about 4,0 c/kg of fibre for the RF dyeing process.

SUMMARY AND CONCLUSION

The dyeing of various synthetic fibres (polyester, acrylic and nylon) as well as wool using radio frequency energy was studied. Some fastness properties of the acrylic, nylon and polyester fibres dyed according to this method were determined. In the case of polyester, good fixation of dye was obtained when the fibres were dyed to a pale shade and the rinsing and reduction clearing water gave ratings of 5. The fastness to washing of the dyed polyester fibres was also very good (rating 5). When the concentration of dyestuff was increased, however, the fixation of the dyes deteriorated to unacceptable levels, even when relatively high levels of carrier were used. This was probably due to the fact that the maximum temperature attainable in the polypropylene dyeing tube was approximately 116°C. The application of higher temperatures during dye fixation should overcome this problem and a glass tube together with a discharge system in which temperatures up to 125°C can be attained is now being installed in the machine. As far as the dyeing of nylon and acrylic fibres are concerned, however, very promising results were obtained. The washfastness and lightfastness ratings of the dyed fibres were good and no dye could be removed from the dyed fibres by rinsing treatments. Photomicrographs of cross-sections of the fibres showed no signs of ring dyeing.

The amount of energy consumed during radio frequency dyeing was determined and a comparison made between the radio frequency dyeing energy cost and that of conventional aqueous dyeing processes. This study revealed significant differences between the two processes in terms of dyeing energy costs (per kg fibre). When the radio frequency dyeing energy cost was compared with the average value reported for conventional aqueous dyeing processes used by South African mills, it was found that the former was about 80% lower than that reported for the latter case. When labour, water and effluent costs were included in the analysis a saving of 40% was obtained with the radio frequency technique.

Finally, a cost analysis was carried out, based on a mill considering the re-equipment of their dyehouse. In this case factors such as depreciation, production cost and return on capital were considered for the cases where either a conventional or a radio frequency dyeing machine was to be purchased. The analysis indicated an added advantage of 4,0 c/kg for the RF dyeing process. It is quite clear, therefore, that radio frequency energy for dye fixation offers significant technical and economical advantages for the dyeing industry and that the use of radio frequency energy for dye fixation has great potential.

It must be pointed out that the cost analysis was based on average costs for the conventional dyeing process. Mill management who wishes to compare the RF dyeing costs with their own conventional dyeing costs should merely substitute the values in the Table with their own specific values.

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THE USE OF PROPRIETARY NAMES

The fact that products with proprietary names (® denotes registered trade marks) have been mentioned in this report does not imply that SAWTRI recommends them or that there are not substitutes which may be of equal or better value.

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