Ultrasound Application to Dyeing of Cotton Fabrics with Reactive Dyes

Bademaw Abate[1]
Ethiopian Institute of Textile & Fashion Technology
(EiTEX), Bahir Dar University
Addis Ababa, Ethiopia

K. A. Thakore [2]
Ethiopian Institute of Textile & Fashion Technology
(EiTEX), Bahir Dar University
Addis Ababa, Ethiopia

Abstract: **Globally, the textile dyeing industry had been known to be a major contributor to environmental pollution. This was mainly due to heavy discharges of nonbiodegradable inorganic salts (electrolytes), alkalis, other processing aids and organic matter such as dyes to the dyeing effluent. In this study, ultrasound energy was introduced in the dyeing bath to solve these problems. A bleached cotton woven fabric of good absorbency and whiteness was dyed with two reactive dyes using ultrasonic frequency of 53 kHz to study its effects. The study revealed that the effects were beneficial in terms of reduction in salt requirements, reduction in dyeing temperature and time for a comparable or even higher color yield. Improved color yield was obtained with ultrasound when dyed at temperature (20-50ºC) as compared to high temperature of 60 or 80ºC conventional dyeing. The use of Taguchi method enabled to obtain optimum ultrasonic dyeing conditions. Increased wash and rubbing fastness rating of ultrasound assisted dyeing indicated deeper penetration of dye molecules inside the fiber.**

Keywords—Cavitation; Cotton; Reactivedye; Temperature; Sonication

1. INTRODUCTION

Reactive dyes are soluble anionic dyes which, in solution, are repelled by the negatively charged surface of the cotton fibre. An electrolyte such as sodium chloride or sodium sulphate is added to promote the dye transfer (exhaustion) and penetration (diffusion) into the fibre. Irrespective of the dyeing method and the type of reactive group, almost all of the potentially toxic non-biodegradable inorganic electrolyte [1], inorganic alkali and unfixed dye are discharged to dyeing effluent. The most important parameter affecting exhaustion and "fixation" of reactive dyes are temperature, salt concentration, alkali concentration, liquid ratio, dyeing conditions [2]. Typical dye fixation efficiency in reactive dyeing of cotton fabric is about 65%. The remaining is hydrolysed and unfixed dye. This creates potential environmental problems from a highly-colored effluent with large quantities of dissolved solids and high BOD and COD values [3]. The removal of hydrolyzed and unfixed dye require large amount of water in post dyeing operation. Increased fixation of dye would reduce less amount of water in the wash off process which would reduce in turn the reduced load on waste water treatment and therefore the cost.

There have been a number of developments for improving the quality of effluent for cotton dyeing systems with reactive dyes. These are development of reactive dyes; the use of two reactive groups in a dye molecule results in higher fixation efficiencies [4]. Such improvements in dye fixation efficiency result in significant reductions in the amount of unfixed dye in dyeing effluent. However, their use in industry is often limited by cost considerations. The other development is the chemical modification of cotton to improve dyeing with direct, reactive, sulphur or vat dyes is an emerging area. This research has focused on the introduction of cationic groups to the cotton fibre [5, 6]. In reactive dyeing, cationisation of cotton has been shown to be capable of eliminating the use of inorganic electrolyte and alkali and leaving a reduced amount of unfixed dye. This offers significant environmental benefits. However, the technique has yet to be adopted by industry. This is mainly because cationisation is an additional process step and the treatment itself does not guarantee safer effluent.

Ultrasound waves are the sound waves beyond the range of human audibility .Ultrasound with frequency range of 20-100 kHz is used for increasing the rate of chemical reactions and advancing different physical processes, such as cleaning, emulsion, extraction etc. It enables increasing the rate of the process and achieving same or even better results in comparison to already existing techniques under less extreme conditions than the one used before; for example, lower temperatures and high chemical concentrations of reactants. For the same reason, the process of material dyeing using ultrasound is very important. Observed improvements in ultrasound processes of dyeing generally refer to the phenomenon of cavitation but some other mechanical influences can happen such as dispersion and diffusion [7-9].

In this paper the effect of ultrasound cavitation energy on dyeing of cotton fabrics with reactive dyes has been studied. The aim of this study is to lower salt consumption, time of dyeing and dyeing temperature in presence of ultrasonic waves in order to reduce reactive dyes hydrolysis and diminish effluent load. The research findings have revealed these.

2. MATERIALS AND METHODS

1.1. Materials

Plain weave cotton fabric of 140 g/m^2 weight and 40 Tex warp and 35 Tex weft count construction was desized, scoured and bleached in laboratory for this study. The pretreated fabric was tested had 1 second water absorbency (AATCC 79 – 1995) and 75 CIE whiteness.

2.2. Dyestuffs and Chemicals

The dye selection criteria included process compatibility, commercial usage, and dye-fibre reaction mechanisms and colors yield. C.I reactive red mixture-89157-03-9; 718619-88-6 (Novacron Ruby S-3B) and C.I reactive blue-191877-09-5 (Novacron Brilliant Blue H-GR) Huntsman dyestuffs were used which had been applied at 60° C and 80° C temperatures by the exhaust method respectively.

Sodium chloride, sodium carbonate and non ionic soap used for washing off of dyed fabric were of laboratory reagent used.

2.3. Conventional Dyeing Method

Dyebath was prepared containing the requisite concentration of dye on the weight of the fabric (% owf.). The material-to-liquor ratio was 1:30. The fabric was immersed at 30°C and salt was added after 15minutes. The temperature was raised to 60°C and the dyeing was continued for 30 minutes .Alkali (15 g/l) was added and the temperature was raised to 60°C for Novacron Ruby S-3B and to 80°C for Novacron Brilliant Blue H-GR as recommended by the dyestuff manufacturer. The dyeing was continued for further 60 minutes.

2.4. Ultrasonic dyeing method

The experimental set up used was composed of ultrasonic cleaner with a frequency of 53 kHz and power of 50W. The material-to-liquor ratio was 1:30.The fabric was immersed at room temperature and salt was added after 15minutes.The temperature was raised to 40°C due to ultrasound cavitation energy and the dyeing continued for 40 min (primary exhaustion phase). Then alkali- sodium carbonate (15g/l) was added for Novacron Ruby S-3B and Novacron Brilliant Blue H-GR), the temperature was raised to 50°C and the dyeing was continued for a further 60 min.

2.5. Experimental Design

The experimental design prepared by using Minitab17 (Taguchi design) with 3 levels, 3 factors and 9 runs for each dyestuff. The details are shown in table 2.1.

Table 2.1: Taguchi design of experiment for optimization of ultrasonic dyeing method

Coded			Non-coded		
A	B	C	Dye,%	Salt, g/l	Time, min
1	1	1	0.5	20	40
1	2	2	0.5	35	60
1	3	3	0.5	70	120
2	1	2	1.0	20	60
2	2	3	1.0	35	120
2	3	1	1.0	70	40
3	1	3	2.0	20	120
3	2	1	2.0	35	40
3	3	2	2.0	70	60

2.6. Wash and Rubbing Fastness

Fastness to washing test was performed according to the standard of AATCC 61-2006. After washing, fabric sample and white cotton and polyester fibers stripe were rated (1-5) using grey scale and staining scale. Where 1 means poor fastness and 5 means excellent fastness.AATCC-8:2005: Colour fastness to crocking (AATCC-Crock meter Method) was used for rubbing fastness evaluation. Both dry and wet rubbing fastness were tested and rated (1-5) using grey scale for color change and staining.

3. RESULTS AND DISCUSSION

3.1 Effect of Dye Concentration on Color yield

The relationship between dye concentration and K/S values of the samples were shown for each dyestuff (Novacron Ruby S-3B and Novacron Brilliant Blue H-GR) in the (Fig.3.1). The figures showed that the K/S values increased with the concentration of dye in the dyebath.

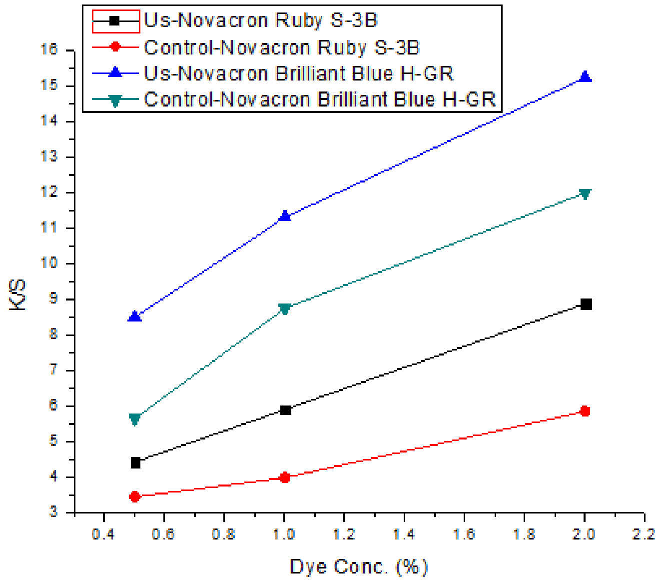

Fig.3.1 Increase in K/S values with dye concentration in the exhaust dyeing (US: With ultrasound, Conventional: without ultrasound).

The correlation analysis showed that there is a positive relationship between dye concentration and K/S (color strength) values for both conventional and ultrasound assisted dyeing. From fig.3.1 K/S values obtained for all dyeing done with ultrasound exhibit increased colour yield as compared to the corresponding values by the conventional dyeing. To obtain a comparative colour yield in case of both dye stuffs the initial dye bath concentration for conventional dyeing it was 2.0% and with ultrasonic dyeing it was 1.0%. So, ultrasound assisted dyeing could reduce the concentration of dye by 50%.

3.2. Effect of Electrolyte Concentration (g/l) on Color Strength

The relationship between salt concentration and K/S values of the samples were shown for each dyestuff (Novacron Ruby S-3B and Novacron Brilliant Blue H-GR in the Figure 3.2) that showed as salt concentration increased the K/S values increased. The correlation analysis showed that there is a positive relation between salt concentration and K/S (color strength) values for both conventional and ultrasound dyeing

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 08, August-2016

methods. From figure 3.2, the K/S values obtained from all US methods have been better than the conventional method.

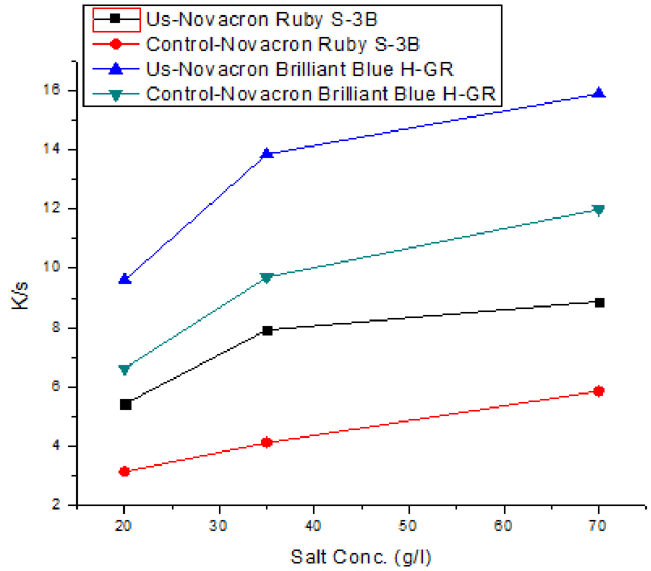

Fig. 3.2 the effect of salt concentration on color yield (US: Ultrasound dyeing, Control-Conventional).

Optimum salt concentration for conventional method was approximated at 70g/l for both dye stuffs .But, the optimum salt concentration for the ultrasonic method appears to be is 35g/l (K/S=7.92 and 13.86 for Novacron Ruby S-3B and Novacron Brilliant Blue H-GR respectively) which gave comparable K/S values of 70 g/l salt concentration (K/S=5.85 and 12.01 for Novacron Ruby S-3B and Novacron Brilliant Blue H-GR respectively) in the conventional method. It plausible therefore that salt concentration can be reduced to half by using ultrasound. The resultant effect would be fewer amounts of dissolved solids in waste water.

3.3. Effect of Dyeing Time on Color Strength

Dyeing time for 40, 60 and 120 minutes, the (K/S) λmax values have been increased for all dyeing methods. The colour strength value for 120 minutes dyeing time was higher than 40 minutes dyeing at all dyeing conditions for all dyeing methods. It has been observed that the (K/S) λmax value of conventional dyed samples have been lower than all with ultrasonic dyeing. As it has been shown in (fig.3.3), 60 minutes ultrasonic dyeing had comparable K/S value to conventional dyeing at 120 minutes. So, the optimum dyeing time for both dyestuffs has been 60minutes for with ultrasonic dyeing while 120 minutes for conventional dyeing (without ultrasound).

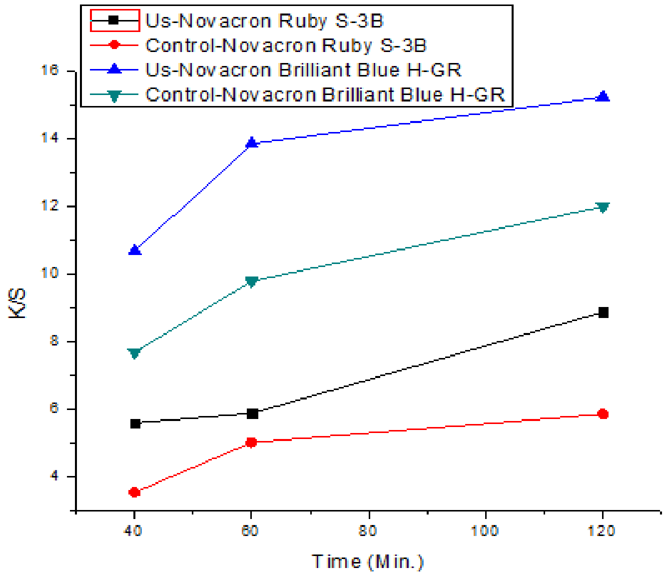

Fig.3.3 The effect of ultrasound on color yield as a function of dyeing time. (US: Ultrasound dyeing, Control-conventional).

3.4. Wash and Rubbing Fastness

Table 3.1 Wash and Rubbing fastness -AATCC Methods

Wash fastness -AATCC 61					Rubbing fastness -AATCC -8			
Dyes	Experiments	Color change	Staining		Color change		Staining	
			cotton	polyester	Dry	Wet	Dry	Wet
Novacron Ruby S-3B	Conventional dyed	4-5	5	5	5	4	4-5	4
	Ultrasound dyed	5	5	5	5	4-5	5	4-5
Novacron Brilliant Blue H-GR	Conventional dyed	4	4-5	5	4-5	4	4-5	4
	Ultrasound dyed	5	5	5	5	4-5	5	4-5

From table 3.1, in both with and without ultrasound (conventional), excellent wash fastness values with respect to color change scale were obtained for Novacron Ruby S-3B reactive dyes. For Novacron Brilliant Blue H-GR dye, a wash fastness rating of 4 in the conventional dyed fabric was less when compared ultrasonic dyed one which was 5 wash fastness rating. This showed that ultrasound had improved the wash fastness with respect to color change scale. The staining on white remains the same regardless whether the dyeing was done with or without ultrasound.

Also, the obtained dry and wet rubbing fastness values showed that the ultrasonic dyed fabrics were very similar or better when compared to conventional dyed ones for both type of dyestuffs. As a result, ultrasound energy had positive effect on the dry and wet rubbing fastness values. This might be due to deep penetration of dye molecules by ultrasonic waves.

4. CONCLUSION

The optimum dyeing condition for the new ultrasonic assisted dyeing had been determined as 1% amount of dye o.w.f, 35g/l salt concentration, 45-55ºC temperature and 60 minutes dyeing time for both dyestuffs. So, ultrasonic dyeing technique could reduce time of dyeing, salts and dyes consumptions by 50%. Spectrophotometric measurements revealed that the ultrasound waves improved colour strength values (k/s values) although dyeing of cotton fabric was conducted at lower temperature.

The deep penetration of dye molecules in ultrasound dyeing improved the wash fastness color change values. In addition, for both dyestuffs when cotton and polyester staining fastness values were considered, color fastness values were comparable with and without ultrasound dyeing. Also, ultrasound had positive effect on the dry and wet rubbing fastness values. So, sonication of the dye bath improved color strength values, fastness properties and reduced effluent loads by minimizing salts and dye stuff consumptions during dyeing.

Therefore, it is highly recommended for textile industrialist, textile machinery manufacturer and Engineers to develop ultrasonic dyeing machine which replace the conventional one to protect the environment, save their economy and get better quality products.

5. ACKNOWLEDGEMENTS

Special thanks to Textile chemistry (Bahir Dar University, EiTEX) Technical Assistants for their valuable cooperation during our laboratory work.

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