(REFEREED RESEARCH)

THE USE OF CONVENTIONAL AND ULTRASONIC ENERGY IN DYEING OF 100% WOOL WOVEN FABRICS

%100 YÜNLÜ DOKUMA KUMAŞLARIN KONVANSİYONEL VE ULTRASONİK ENERJİ YÖNTEMİ İLE BOYANMASI

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ABSTRACT

This paper focuses on the dyeing behaviour of wool woven fabrics produced from 100% wool sirospun and conventional woollen yarns. The ultrasonic energy was applied as a dyeing method and was compared with the conventional dyeing technique. Three wool woven fabrics made of 2/2 Z twill and having different weight of fabrics with different warp and weft densities were produced. Later, optimum dyeing conditions were studied by using two different temperatures and two different times on the ultrasonic energy method. The wool woven fabrics were dyed in both dyeing techniques by using a commercial Dorolan Black MSRL (acidic dye) and later these samples were tested for their colour measurement by a reflectance spectrophotometer. Both dyeing techniques were compared according to the data obtained. It was observed that ultrasonic energy technique was successfully adapted to wool dyeing process. 100% wool wollen fabrics were dyed with the ultrasonic probe at 90oC temperature with the reduce amount of time (64 minutes less than conventional dyeing) compare to conventional dyeing technique. The lighter sirospun wool fabrics (158.6 g) were also dyed easily with the use of ultrasonic energy in all conditions (in both temperatures: 80oC-90oC and in both times: 80min-90min).

Key Words: Ultrasonic energy, Dyeing, Wool, Woven fabric, Colour measurement, Sirospun, Woollen yarn.

ÖZET

Bu makale, %100 yün sirospun ve straygarn ipliklerden üretilen dokuma kumaşların boyanma davranışını incelemektedir. Burada, ultrasonik enerji yöntemi boyama metodu olarak uygulanmış ve konvansiyonel boyama tekniği ile karşılaştırılmıştır. Çalışmada, farklı çözgü ve atkı sıklıkları ile 2/2 Z dimi olmak üzere üç tip yünlü dokuma kumaş üretilmiştir. Daha sonra, ultrasonik enerji yöntemi kullanılarak iki farklı sıcaklıkta ve iki farklı sürede optimum boyama koşulları incelenmiştir. Yünlü dokuma kumaşlar Dorolan Black MSRL (asidik boyarmadde) ile her iki boyama tekniğinde boyanarak renk ölçümleri reflektans spektrofotometrede ölçülmüş ve elde edilen verilere göre her iki boyama tekniği karşılaştırılmıştır. Ultrasonik enerji yönteminin yünün boyanmasında başarılı bir şekilde kullanılabileceği gözlemlenmiştir. %100 straygarn dokuma kumaşlar ultrasonik prob ile 90oC sıcaklıkta ve kısaltılmış sürede (konvansiyonel boyama tekniğine gore 64 dakika daha kısa sürede) boyanabildikleri görülmüş ve konvansiyonel boyama tekniğiyle kıyaslanabilmiştir. Ayrıca, ince sirospun ipliklerden üretilen yünlü dokuma kumaşlar (158.6 g) ultrasonik enerji yöntemi ile çalışılan boyama koşullarında (her iki sıcaklıkta: 80oC-90oC ve her iki sürede: 80min-90min) rahatlıkla boyanmışlardır.

Anahtar Kelimeler: Ultrasonik enerji, Boyama, Yün, Dokuma kumaş, Renk ölçümü, Sirospun, Straygarn iplik.

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1. INTRODUCTION

Textile materials can be in different forms such as loose fibres, spun and filament yarns, woven and knitted fabrics or non-woven materials. Even though, form of the material may define the best type of machinery on a commercial scale, it is the nature of the fibre itself that guides the process to be used. The idea of implementing ultrasonic energy to textiles, especially for the wet finishing processes (1), (2), (3), (4), (5) has been initiated since 1990s; in these works generally ultrasonic energy was applied to dyeing of textiles. On the other hand, dyeability properties of bleached cotton yarns and woven fabrics (6) and washing of medical surgery gowns were studied by the ultrasound technique (7) and it has been discovered that ultrasonic energy can be used to enhance removing the stains on the fabrics and the ultrasonically treated fabrics have shown less tenacity loss than the conventional methods. Although several researches (5), (6), (7) on ultrasonic energy have been used in textiles for some era, generally it has been considered as an alternative process to the conventional methods to accelerate mass transfer in textile materials in recent years. Especially, the use of ultrasonic energy in wet finishing processes has a potential in decreasing the amount of the process time, energy, chemicals used in and in improving product quality (8). A recent work (9) was carried out on industrial size ultrasound bath for textile treatments and it was stated that textile material type, bath temperature and volume may lead to significant changes at sound pressure level of the ultrasound bath for the textile industry.

Although dyeing technique applied so far in wool textile industry is still conventional dyeing in the literature (10) it was noted that ultrasonic energy may increase the dyeing effect of wool with lac dyes. From this point of view, we have applied a novel dyeing technique by using of ultrasonic energy on to the wool fabrics in a laboratory scale to be able to see if an alternative method of dyeing can be established with an acidic dye or not. For this purpose, we produced 100% wool fabric made of both sirospun yarns and conventional yarns. Later, the colour differences in both woven fabrics (made of a conventional yarn and two sirospun yarns) were reported on both dyeing techniques.

2. MATERIALS AND METHODS

Three wool woven fabrics made of 2/2 Z twill were used in the experimental study. Both yarns and fabrics were specially produced under very strictly controlled mill conditions. The sirospun yarns and woollen yarns of the woven fabrics were spun from the same fiber batch which is 70 mm in length and 19-21 µ. The produced yarn properties are given in Table 1 and the produced raw woven fabric properties are shown in Table 2.

After weaving, the woven fabrics were scoured with 1g/L of nonionic scouring agent (Tanaterge LFN), the liquor ratio was chosen 1/60 and the temperature was kept 50°C for 20 min. and later all the fabrics were left to dry under room temperature before dyeing. Two different dyeing methods were applied for all the wool woven fabrics.

2.1. Conventional dyeing

The dyeing of the wool woven fabrics was performed under laboratory conditions in a laboratory-type sample dyeing machine (Roaches lab machine). In the conventional dyeing experiments, the woven fabric samples weighed 3 g and the liquor ratio was 40:1. The samples were dyed with a acidic dye (Dorolan Black MSRL of 4.9 % over weight of fibre-owf). The dyeing experiments were performed according to the dyeing procedure recommended by the dyestuff manufacturer (EVRON) for the sample dyeing machine (see Table 3).

The dyeing process started at 40°C. After 10 minutes the dye is added and the temperature was maintained for 10 minutes and than raised to 100°C at a rate of l°C/minute. The dyeing continued at this temperature for 60 minutes to allow a good penetration of the dyes and level dyeing. Later the dye bath cooled to 80°C at a rate of 5°C/minute. After dyeing completed the samples were taken out of the dyeing tubes and post-treated. The post-treatments of the dyed samples were made at a liquor ratio of 100:1. The samples were rinsed with cold water for 10 minutes. After rinsing the samples were left to dry under laboratory conditions.

2.2. Dyeing with the ultrasonic energy

In the alternative dyeing technique (see Figure 1), which was also studied in this work is the use of ultrasonic energy and was carried out with the BRANSON ultrasonic probe at 20 kHz. The dyeing recipes are shown in Figure 1. In this dyeing process, the woven fabric samples again weighed 3 g and the liquor ratio was 40:1. The dyebaths also contains same chemicals as in conventional dyeing (see Table 3). The dyeing process started at 40°C. After 10 minutes the dye is added and the temperature was maintained for 10 minutes and than raised to 80-90°C in 20 minutes and maintained dyeing 40-50 minutes to allow a good penetration of the dyes and level dyeing. Later the dye bath cooled to 40°C at a rate of 5°C/minute.

Table 1. Wool yarn properties

Yarn parameters	Sirospun			Woollen yarn
Yarn count (Nm)	90/2	48/1	70/2	66/2
Twist (T/m)	950	650	750	450

Table 2. Wool woven fabric properties

Fabric parameters	A	B	C
Produced yarn type	Sirospun	Sirospun	Woollen yarn
Structure	2/2 Z twill	2/2 Z twill	2/2 Z twill
Weight of fabric (g/m^2)	158.6	243.3	197.8
Weft density (thread/cm)	40	32	30
Warp density (thread/cm)	40	30	25

Table 3. Chemicals used in both dyeing techniques

Chemicals	**Amount**
Dorolan Black MSRL (78% acidic dye concentration	4.9 % owf
Doregal PAWO (levelling agent)	0.5 % owf
Glaubers's salt (anhydrous)	5 % owf
CH_3COOH - CH_3COONa (buffer solution)	0.5–0.15 ml
Tanaterge LFN (wetting agent)	1g/L

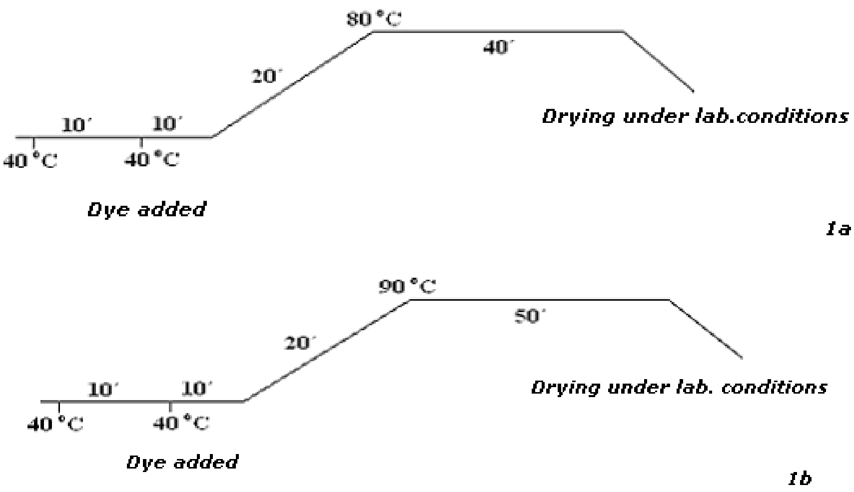

Figure 1. Dyeing diagrams with the use of ultrasonic energy

Table 4. Parameters used for the dyed fabrics

	X_1	X_2	X_3
	Temperature(°C)	Time(min.)	Fabric type
Level 1	80	80	A
Level 2	90	90	B
Level 3	-	-	C

Table 5. Effects of dyeing condition with the use of conventional dyeing on the CIELab values of acidic dyed fabrics

Fabric	**Dyeing Condition**	**L***	**a***	**b***	**C ***	**h**	**K/S**
A	100°C, 144min	14.95	0.66	-0.99	1.19	303.83	26.54
B	100°C, 144min	12.30	0.61	-0.88	1.07	304.80	35.50
C	100°C, 144min	12.72	0.68	-1.14	1.33	300.60	33.92

After dyeing completed the samples were taken out of the dyeing tubes and post-treated. The post-treatments of the dyed samples were made at a liquor ratio of 100:1. The samples were rinsed with cold water for 10 minutes. After rinsing the samples were left to dry under laboratory conditions.

The colour coordinates of both dyeing techniques (Roaches lab machine and probe of ultrasonic energy) of the samples were measured on the reflectance spectrophotometer (Datacolor SF 600plus) coupled to a PC under D65/10^0 illuminant with specular component included. The conventional dyed fabrics were taken as the standards. The color differences, according to the CIELab (1976) equation, were obtained from the color measuring software. Four reflectance measurements were made on each sample rotating the samples 90° before each measurement. The average of the measurements of the two samples was recorded as color differences (ΔE) and colour yield (K/S).

The colour difference is expressed as ΔE and is calculated by the following equation (11), (12):

$$\Delta E^* = ((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2)^{1/2} \quad \ldots \quad (1)$$

where ΔE^* is the CIELab colour difference between batch and standard. Here ΔL^*, Δa^*, Δb^* and hence ΔE^* are in commensurate units. ΔL^* denotes the difference between lightness (where L^* =100) and darkness (where L^* =0), Δa^* the difference between green ($-a^*$) and red ($+a^*$), and Δb^* the difference between yellow ($+b^*$) and blue ($-b^*$).

On the other hand, the Kubelka-Munk equation relates the absorption function of the substrate (K), the scattering function of the substrate (S) and the reflectance (R) according to the equation (2), given below (13).

$$K/S = \frac{(1-R)^2}{2R} \quad (2)$$

2.3. Statistical analyses of dyed fabrics by the use of ultrasonic energy

To be able to give a better picture of understanding the effects dyeing parameters on the use of ultrasonic energy, the ΔE values of the dyed fabrics were also mathematically analysed by the use of Minitab Release 13.20 software programme. The parameters used for the mathematical model is given in Table 4.

3. RESULTS AND DISCUSSION

Effects of fabric properties on the CIELab values of the conventionally dyed wool fabrics

Table 5 shows the L^*, a^*, b^*, C^*, h and K/S (colour yield) of the acidic conventional dyed wool fabrics by the use of Roaches lab machine. It was observed that the more heavily the fabric (weight of fabric A<C<B) the darker it gets after conventionally dyed with the Dorolan Black MSRL (see L* values in Table 5). On this account, fabrics with higher weight presents higher colour yield (K/S) and therefore this indicates that the reflectance decreases; hence heavier fabrics absorbs more dyes.This might be also from the twist present within the yarns of these fabrics are lower than the other woollen fabrics and therefore more dyes were easily absorbed within the structure of the heavier fabric than the others.

Table 6. Effects of dyeing condition with the use of ultrasonic energy on the CIELab values of acidic dyed wool fabrics

Fabric	Dyeing Condition	L*	a*	b*	C *	h	ΔE	K/S
A	80°C, 80min	17.64	1.28	-2.13	2.49	300.94	0.887	25.90
	80°C, 90min	14.76	1.06	-1.44	1.79	306.37	0.631	28.83
	90°C, 80min	14.19	0.82	-0.73	1.10	318.63	0.828	29.23
	90°C, 90min	14.25	0.83	-0.99	1.29	310.18	0.583	28.23
B	80°C, 80min	18.10	1.27	-2.35	2.67	298.47	4.446	21.48
	80°C, 90min	15.80	1.24	-2.06	2.40	301.12	3.748	26.00
	90°C, 80min	14.20	1.10	-1.88	2.17	300.31	0.692	30.53
	90°C, 90min	12.98	0.96	-1.47	1.76	303.21	0.967	33.84
C	80°C, 80min	16.08	1.29	-2.42	2.74	298.01	2.759	26.05
	80°C, 90min	13.84	1.09	1.68	2.00	302.83	1.303	26.64
	90°C, 80min	12.67	0.98	-1.19	1.54	309.56	0.312	34.24
	90°C, 90min	12.99	0.89	-1.56	1.80	299.68	0.547	33.62

Effects of dyeing condition on the CIELab values of the dyed wool fabrics by the use of ultrasonic energy

Table 6 represents L^*, a^*, b^*, C^*, h, ΔE values and K/S (colour yield) of the acidic dyed wool woven fabrics by the use of ultrasonic energy. From the Figure 2 it was seen that, the more acceptable ΔE values (ΔE < 1) were obtained for the lighter fabric made of sirospun yarn (fabric A) in all conditions of the ultrasonic energy. For the heaviest fabric which is produced from the sirospun yarn (fabric B) has shown good improvement on ΔE values at both dyeing durations (80 min and 90 min) with the increase of temperature from 80 °C to the 90°C (see Figure 2 for the fabric B). On the other hand, the best overall ΔE values were obtained on the fabric C, which is made of woollen yarn (see Table 2), at the 90°C with both dyeing durations (80 min and 90 min), see Figure 2.

As importantly K/S value of a dye is related to the concentration of the dye on the textile material, i.e. the magnitude of the value is a direct measure of dye depth shade. Therefore, from the Table 6 it can be said that the highest K/S value was obtained on the C fabric at 90°C and 80 min of dyeing process.

As seen from Figure 3, effects of dyeing temperature and fabric type are much more important than the dyeing time of wool fabrics when dyed with the use of ultrasonic energy. As it is known that the lower the ΔE value is the best therefore, it can be stated that the best ΔE values are obtained at 90 °C and on the fabric A (158.6 g). Also, the higher the temperature may result a better ΔE values on the wool fabrics with the dying of ultrasonic energy.

Similarly if interaction parameters are studied it can be seen from the Figure 4 that, both fabric A with 90 min of dyeing and fabric A with 90 °C gives better ΔE values than the rest of dyeing conditions.

The regression equation of the ΔE values of the wool woven fabrics which are dyed with the use of ultrasonic energy are also given below:

$$\Delta E = 14.3 - 0.164\, x_1 - 0.0357\, x_2 + 0.0206\, x_3 ,\quad R^2 = 69.3\% \qquad (2)$$

where x_1: temperature (°C,) x_2: time (min) and x_3: fabric (g).

From the given equation (2) and within the parameters level (x_1: 80°C-90°C, x_2: 80min.-90 min and x_3: 158.6g-243.3 g) the colour differences of the wool woven fabrics can be estimated for the future studies.

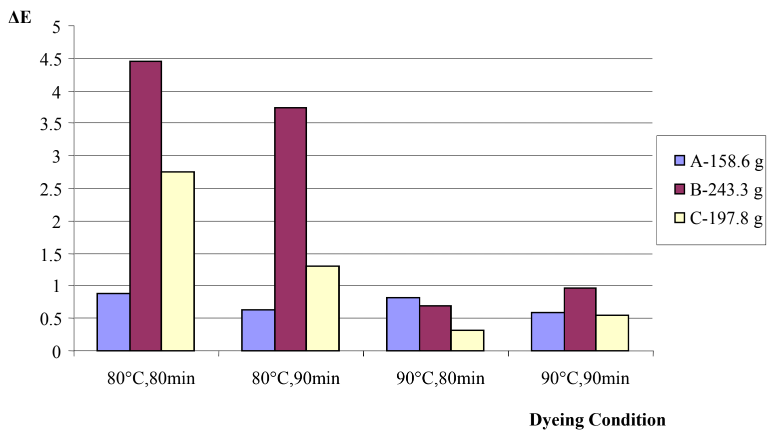

Figure 2. Effect of dyeing conditions on the ΔE values of the wool woven fabrics dyed with the use of ultrasonic energy

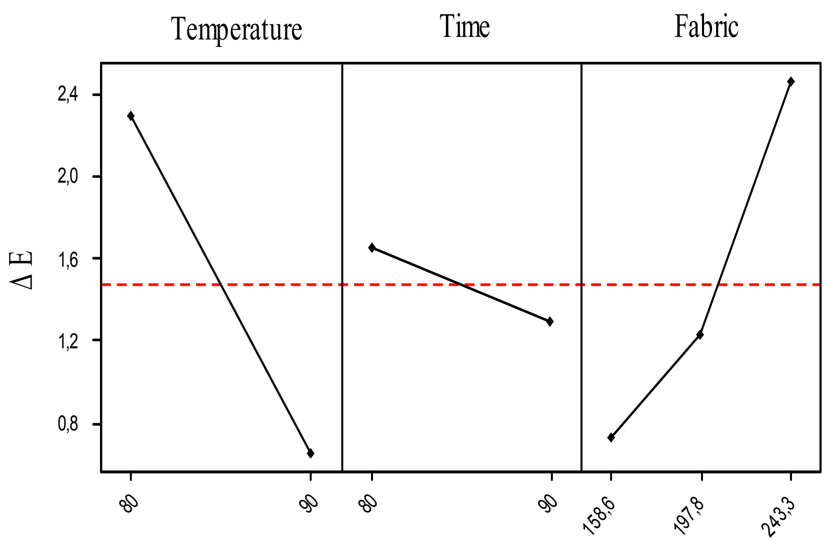

Figure 3. Main effects on the ΔE values of the wool woven fabrics dyed with the use of ultrasonic energy

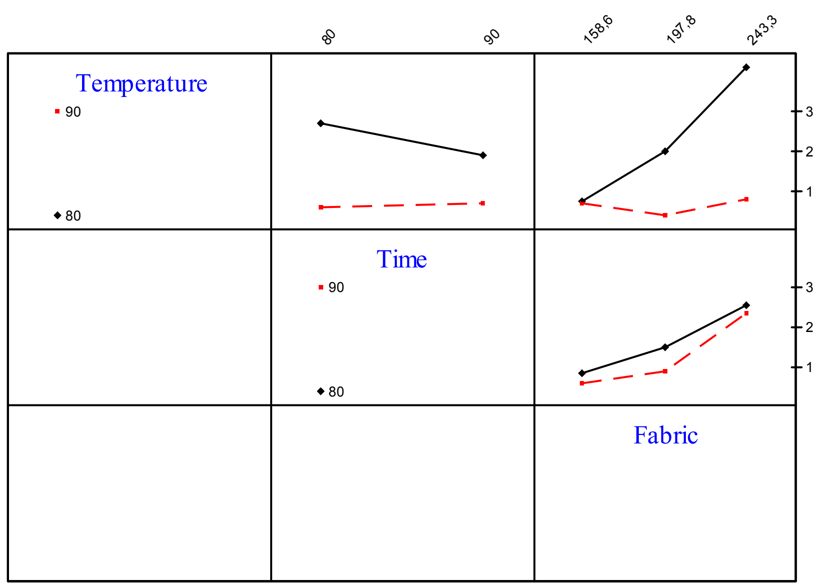

Figure 4. Interaction effects on the ΔE values of the wool woven fabrics dyed with the use of ultrasonic energy

4. CONCLUSION

The effects of yarn types and fabric weights on colour difference values (ΔE) of the 100% wool fabrics were considered using conventional dyeing and ultrasonic energy techniques. With this current study, ultrasonic energy technique was successfully adapted to wool dyeing process.

It was observed that 100% wool wollen fabric (spun from Nm 66/2 and fabric weight 197.8 g) has been dyed most successfully within the fabrics with the acidic dyestuff (Dorolan Black MSRL) at 90^{o}C temperature for a period of 80 min. dyeing time by the use of ultrasonic energy; the colour difference value for this fabric was (ΔE=0.312) and the K/S value was 34.24; this indicates that dye depth shade is good and this correlates with acceptable ΔE value of the fabric. The reason for this might be the twist in the yarn is lower and the weft and warp densities are lower than the other two fabric types and therefore dyes can be much more easily absorbed by this type of fabric by using the ultrasonic energy.

In general, the best dyeing condition for the wool fabrics was 90^{o}C, 80min where both ΔE values are acceptable and K/S values are higher than the rest of the dyeing conditions of the ultrasonic energy. The lighter weight of sirospun wool fabric A (158.6 g) was without difficulty dyed with the use of ultrasonic energy in all conditions; although the colour difference values were acceptable (ΔE <1) in all dyeing conditions the highest K/S value (29.23) was obtained at the 90^{o}C, 80min of dyeing process. On the other hand, the sirospun wool fabric B, which has the lower weft and warp density than the A fabric, has shown slightly better K/S value than the A fabric. This also indicates that sirospun wool fabric made of lower twisted yarn and less yarn densities may absorbed more dye with the use of ultrasonic energy than the A fabric.

As a result, 100% wool fabric, which is either made of woollen yarn or sirospun yarn, can be dyed with the use of ultrasonic energy rather than the conventional dyeing. In overall results, the wool fabrics have presented similar colour yield (K/S) and acceptable colour differences (ΔE) with the use of ultrasonic energy.

Finally, we believe that ultrasonic energy can be an advantage to use for wool dyeing at lower temperatures (such as 80°C and 90°C) and lower dyeing times (i.e. 80min. or 90min) as an alternative process for conventional dyeing (100°C and 144 min).

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