DYEING OF COTTON FABRIC WITH REACTIVE DYE USING INFRARED HEATING TECHNIQUE

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Abstract

A new technique represented in this study for evaluating the performance of dyeing cotton fabrics using infrared (IR) heating technique compared to conventional exhaust dyeing method. The effect of this new technique has been studied on the color strength (K/S), color fastness properties, tensile strength and elongation of the dyed cotton fabrics made of two Egyptian varieties Giza 90 and Giza 95 using Procion H-EXL blue reactive dye with concentrations 2%, 4% and 6% . The color strength values of the infrared heating technique in dyeing were better than those of the exhaust dyeing obtained using the same dye concentration 4% and the same recipes. Also the results for dyeing using infrared heating technique had no bad effect on the color fastness or on the dyed cotton fabric mechanical properties.

Keywords: Cotton, reactive dye, infrared rays.

INTRODUCTION

Many different heating and drying processes are required in processing of textiles, such as dyeing and finishing which are needed to be as quick as possible. Thus, the requirements for heating sources are increased (Heraeus, 2019).

Infrared radiation (IR), is an electromagnetic wave with longer wavelengths than the visible light, thus it is invisible to the human eye (Liew, 2006). Table (1) shows the comparison of different kinds of light (Haynes, 2011).

Table 1. Comparison of electromagnetic waves

Electromagnetic waves type	Wavelength	Frequency (Hz)
Gamma ray	less than 0.01 nm	more than 30 EHz
X-ray	0.01 nm – 10 nm	30 EHz – 30 PHz
Ultraviolet	10 nm – 400 nm	30 PHz – 790 THz
Visible	400 nm–700 nm	790 THz – 430 THz
Infrared	**700 nm – 1 mm**	**430 THz – 300 GHz**
Microwave	1 mm – 1 meter	300 GHz – 300 MHz
Radio	1 meter – 100,000 km	300 MHz – 3 Hz

Infrared waves are considered to be in the lower-middle range of wave frequencies that is between microwaves and visible light. Infrared waves with longer frequencies produce heat such as fire, the sun and other heat producing sources. On the other hand, infrared waves with shorter frequencies do not produce high heat so, they are used in other technologies such as remote controls (Braybury, 2018).

Infrared heating is commonly performed in textile finishing specially in textile coating applications. Heating textile is performed through one of three types of heat transfer: convection, conduction, or radiation. Each type has its advantages and disadvantages (Van Denen, 1993).

Infrared is used as a heating source in textile processing due to its heating power in a short time, which helps to decrease energy consumption and increase the speeds of production that's leading to lowering the production costs (Heraeus, 2019).

Infrared heat transfer is unique compared to convection and conduction because the heat transfer is considered to be a heat source which transfers large quantities of heat energy to the fibers in a short amount of time (Van Denen, 1993). The infrared process is an environmental technique that reduces pollution by decreasing the waste dyes and electrolytes in the effluent from reactive dyeing, because of the high fixation that occurred using the infrared heating technique compared to other conventional dyeing techniques (Broadbent, *et al.,* 2005) and (Debasree, *et al.,* 2017) .

Infrared technology represents an alternative to conventional drying. With the application of water-based equipment and textile coatings, the production process can be reorganized and made more efficient especially in processes such as drying, thermal fixing or coating, etc, which usually have high energy requirements. However, not every infrared emitter is suited for each process (Eckert, 1994).

Reactive dyes are dyes which include a reactive centre, which reacts with a nucleophilic group (conventionally on the material of the textile being dyed) to form a covalent bond, which strongly bonds the dye to the fiber. The reactive centre is typically an electrophilic centre, often associated with a reactive group. Reactive dyestuffs can include more than one reactive group and may have more than one type of such groups. Procion type dyes are examples of these classes of dyestuffs (Collins, *et al.*, 1998).

The efficiency of infrared heating relies on the spectral absorption of the fabric and the spectral emission of the infrared emitter. Carr *et al.,* (1997) evaluated the effects of using IR emitters on fabric properties, such as fabric type, weight, construction, and dyeability. This study reported that it is useful to match infrared heating in textile industry applications.

Broadbent *et al.* (2007) investigated dyeing of polyester and cotton/polyester blend using disperse and reactive dyes. The dye fixation was done using an electric infrared oven. The color strength values using the infrared heating were similar to those of the conventional exhaust dyeing. Using infrared heating didn't affect the light fastness of the colors or on the fabric characteristics. Thermal dyeing using infrared rays demonstrated that the dyeing process was totally controlled which was valuable for the fabrics dyeing. Broadbent *et al*. (1998) studied dyeing cotton fabric using reactive dye where the reaction between the dye and the cellulose chains accelerated by using an electric infrared heating source. The study demonstrated that infrared dye fixation was higher and faster, than those for conventional dyeing produced by other heating sources, especially for the lower reactivity dyes.

MATERIALS AND METHODS

Materials

Woven Egyptian cotton fabrics made from the two long staple cotton varieties for middle and Upper Egypt namely; Giza 95 and Giza 90 were used. Some specifications of these fabrics are shown in Table 2.

Table 2. Specifications of the cotton fabrics.

Fabric Specifications	**Giza 95**	**Giza 90**
weave construction	plain	plain
warp yarn count	40	40
weft yarn count	40	40
mass per unit area	175 g/m2	180 g/m2

Specimens of size of 25 cm x 25 cm were scoured and mercerized.

All chemicals used were of analytical grade. Glauber's salt ($Na_2SO_4.10H_2O$) and NaOH were analytical grade (Koch-Light Co.), Sodium chloride (LR grade), the wetting agent was the commercially Triton X-100 supplied by Merck. The reactive dye used in this study was Procion H-EXL blue, which has two cyanuryl chloride structure each of them having one remaining chlorine atom (Collins, 1998) as the Structural formula shown in Figure 1.

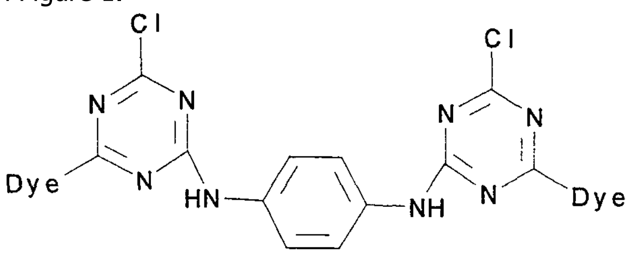

Fig. 1. Procion H-EXL Blue chemical structure

Methods:

1. Scouring:

Cotton fabrics were boiled for 1.5 hours in alkaline solution containing sodium hydroxide (4.0 %) and wetting agent (Triton X-100) using liquor ratio (1:50 w/v). Then rinsing with hot and cold water then air dried at room temperature (Al Ashwat, 1974).

2. Slack mercerization:

The scoured fabrics were mercerized according to Khalifa, (2017) by using NaOH solution (20 %), the liquor ratio was (1:50 w/v) at 20°C for 2 min. The samples were washed with boiled and cold water several times to remove the excess caustic soda. Finally the samples were neutralized using acetic acid solution (10 %), followed by cold rinsing step, finally dried the cotton fabrics at 80-100˚C.

3. Dyeing:

Both scoured and mercerized samples were dyed with different concentrations (2%, 4% and 6%) of Procion H-EXL Blue reactive dye, using two different dyeing heating techniques (conventional and Infrared), The Infrared rays as a heating source was used by ideal laboratory dyeing machine as shown in Figure 2 (Yabo Inc, Jiangsu, China) at Cotton Chemistry Research Department, Cotton Research Institute, Agricultural Research Centre, Giza, Egypt. Figure 3 shows the dyeing procedure curve using the both heating techniques. After dyeing, soaping was performed with 2 g/L detergent at 90ºC for 10 minutes and finally the samples were dried according to Debasree, *et al.,* (2017).

Fig.2. Infrared laboratory dyeing machine (Yabo Inc, Jiangsu, China)

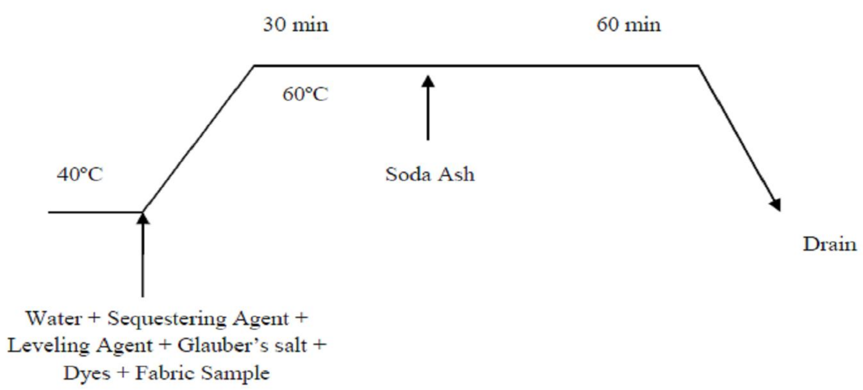

Fig. 3. Dyeing procedure curve

Measurements

1. Color Strength (K/S).

The reflectance value of a specimen for the wave length of 400nm–700nm with 10nm intervals was evaluated using UV/VIS spectrophotometer (Lambda 35, Perkin-Elmer, USA). The measurement was performed in accordance to ASTM E313-96 using CIE color system coordinates. By using this reflectance value into the Kubelka Munk's equation color strength (K/S) can be determined.

$$K/S = (1- R)^2/2R$$

Where, R=Reflectance of an incident light from the dyed material, K=Absorption, and S= Scattering coefficient of the dyed fabric.

2. Color Fastness Properties.

Color fastness properties of all dyed specimens were determined as following:

- Wash-fastness properties of the samples were measured according to ISO 105-C01, and the staining colors were assessed by the gray scale.
- Light-fastness measurements according to ISO 105-B01
- Perspiration fastness was measured according to ISO 105-E04:1987

3. Tensile strength and elongation.

The tensile strength (g/tex) and elongation (%) were measured using Zweigle testing machine, at a tension speed of 100 mm/min under the standard atmospheric. The testing was performed according to ASTM D412-98a. Statistical procedure: The analysis of Variance (ANOVA) statistic was done by SPSS software version 16 (2008).

RESULTS AND DISCUSSION

1. Effect of the dye concentration on Color Strength (K/S)

Figure (4) exhibits the effect of Procion H-EXL blue dye concentration (2%, 4% and 6%) on the color strength (K/S) of the dyed cotton fabrics. The results showed that the K/S values generally increased as the dye concentration increased.

The color strength (K/S) values for Giza 95 scoured and mercerized dyed fabrics, respectively were 2.28 and 3.01 when using the minimum dye concentration (2%), while it was 3.11 and 3.46 with (4%) dye concentration ,however it was 3.22 and 3.88 when using the high dye concentration (6%).

On the other hand , the color strength (K/S) values for Giza 90 scoured and mercerized dyed fabrics, respectively were 2.87 and 3.36 when using (2%) dye concentration, while it was 3.32 and 3.81 using (4%) dye concentration ,however it was 3.5 and 3.92 at dye concentration (6%).

Meanwhile, the highest value of K/S is observed for mercerized dyed fabrics compared with the scoured fabrics for both cultivars G.90 and G.95, which means that the mercerization has a greater impact on the values of dye uptake for cotton fabrics because mercerization swells the fibers and the molecular structure becomes open, thus facilitating the dye uptake and a higher K/S value is obtained (Khalifa, 2017).

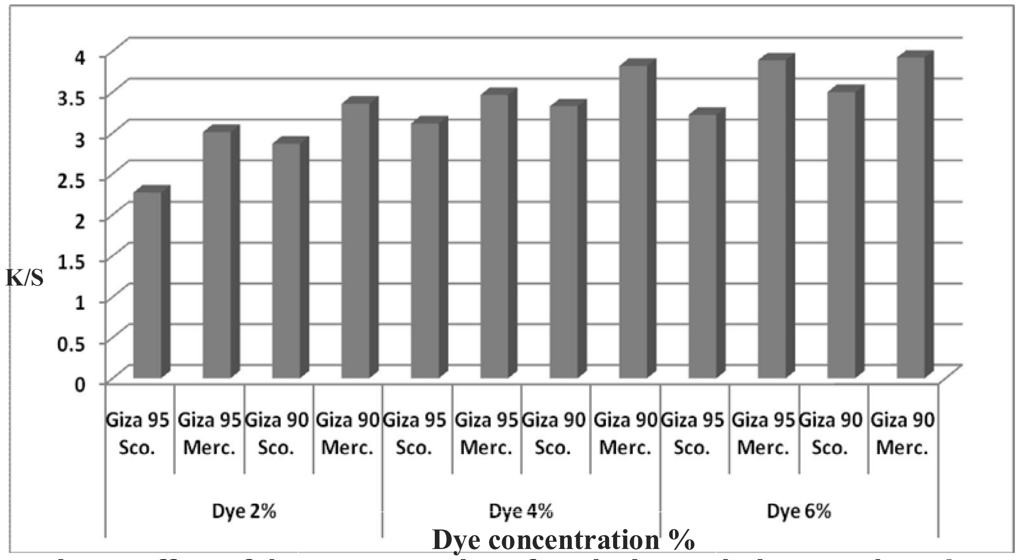

Fig. 4. Effect of dye concentration of IR dyeing technique on the color strength (K/S) of the cotton dyed fabrics.

As a results of the effect of dye concentration of IR dyeing on color strength (K/S) of cotton dyed fabrics, the K/S values for dye concentration (4%) showed recommended concentration for the conventional technique. Figure (5) shows the color strength values for both conventional exhaustion and the infrared dyeing techniques using (4%) dye concentration. It is observed that the infrared dyeing generally has better results when compared to conventional technique. On the other hand the color strength (K/S) values for Giza 90 dyed fabric were higher than those of Giza 95. This is may be due to cellulose orientation and fiber genotype characteristics.

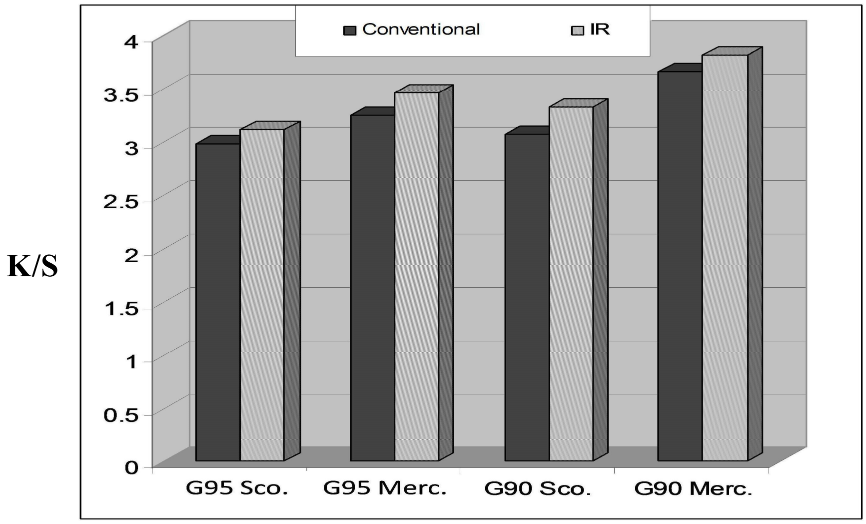

Fig.5. Comparison of IR and conventional dyeing techniques on color strength (K/S) of the cotton dyed fabrics

2. Mechanical properties of cotton dyed fabrics as affected by conventional and IR heating techniques.

The mechanical properties of the dyed cotton fabrics are shown in Table (3). The results showed that the slack mercerization treatment caused a slight decrease in the tensile strength (g/tex) and marked increase in the elongation (%) of the dyed samples. It could be due to the effect of the slack mercerization on the orientation and re-arrangement of the cellulose chains. This result was in agreement with Mahmoud, *et al.,* (2005).

Generally the results showed that the effect of different pretreatments (scouring & mercerizing) and dyeing methods (conventional & infrared) of the cotton fabrics were insignificantly for the fabric tensile strength, while the elongation (%) was affected significantly after the slack mercerization treatment for the both cultivars (G 90 and G 95).

Table 3. Analysis of variance for mechanical properties of un-dyed/dyed cotton fabrics using IR and conventional dyeing techniques

Cotton fabrics	pretreatment	Dyeing technique	Tensile Strength			Elongation		
			g/tex	F value	P value	%	F value	P value
G.95	Scoured	Un-dyed	36	4.43	0.066	27	2.00	0.216
		conventional	38			25		
		Infra red	38			26		
	Mercerized	Un-dyed	35	5.08	0.051	35	10.5	0.011*
		conventional	37			36		
		Infra red	36			38		
G.90	Scoured	Un-dyed	35	0.63	0.564	28	0.86	0.471
		conventional	36			27		
		Infra red	36			27		
	Mercerized	Un-dyed	34	1.20	0.364	37	6.86	0.028*
		conventional	34			39		
		Infra red	35			38		

*Statistically significant at P value <0.05 based on Analysis of Variance (ANOVA) statistics.

3. Color fastness

Table (4) shows the color fastness measurements (washing, perspiration and rubbing fastness) for the cotton fabrics dyed with the procion H-EXL blue reactive dye using infrared heating technique.

Table 4. Fastness properties of the cotton fabrics dyed with reactive blue dye using infrared heating technique

Cotton Fabric	Pretreatment	Color Fastness to:				
		Washing	Rubbing		Perspiration	
			wet	dry	Alkaline	Acidic
Giza 95	Scoured	4-5	3	3-4	3-4	3
	mercerized	4-5	3-4	4	4	3-4
Giza 90	scoured	4-5	3	3-4	3-4	3
	mercerized	4-5	3-4	4-5	4	4

The results showed that generally color fastness to washing ranged from good to excellent (4-5). Also the mercerized dyed Fabrics displayed excellent grade in color fastness compared to un-mercerized.

Regarding the dry and wet rubbing fastness the high values of the rubbing color fastness indicate the higher color depth and strength onto the fabrics. The results showed that the wet rubbing properties are lower than dry rubbing. The minimum range for rubbing fastness was 3 and maximum range was 5. Debasree., *et al.* (2017), reported that when the dyed samples are rubbed against an object, more dye molecules come out from the fabric surface, hence the value becomes less, which means rubbing fastness property is not good.

Meanwhile, the results observed that the fastness against acidic perspiration is lower than the alkaline perspiration. Also it was observed that the minimum range for the both perspiration fastness was 3 and maximum range was 4.

Generally the results clearly showed that, the two Egyptian cotton varieties (G 95 and G 90) responded almost equally regarding the overall color fastness, it could be due to they are from the same long staple category of Egyptian cotton varieties. Also it is worthwhile to mention that the overall good fastness results could be explained by the infrared fixation process that gave high dye fixation with no color change (Broadbent, *et al.,* 1998).

CONCLUSION

The Egyptian cotton fabrics were dyed with different concentrations of reactive dye using both conventional exhaustion dyeing method and IR laboratory sample dyeing machine in which the infrared is the source of heating. A better color strength was found in mercerized samples in both dyeing techniques. The color fastness to washing, rubbing and perspiration for the dyed fabrics are found to be good to excellent. However, the optimum condition of dyeing was obtained using 4% dye concentration at 60ºC using IR dyeing for 45 minutes.

Moreover using the Infrared rays as heating source in the dyeing machine is friendly for environment, as there are no fumes and no resulting pollution. Heating is uniform and temperature sensing is accurate, and reducing the unfixed dyes in the effluent of dye factories**.**

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صباغة الأقمشة القطنية بالصبغة النشطة باستخدام تقنية التسخين بالاشعة تحت الحمراء

شيرين عمر بهلول

معهد بحوث *القطن – مركز البحوث الزراعية – جيزة*

تم اجراء هذه الدراسة لتقييم اجراء عملية الصباغة للأقمشة القطنية بطريقتين : الأولى بطريقة الصباغة التقليدية و الثانية باستخدام الاشعة تحت الحمراء كمصدر حراري في عملية الصباغة بماكينة (IR dyeing machine) كتقنية حديثة للصباغة وذلك لصنفين من أصناف القطن المصري طويل التيلة للوجه القبلي وهما : جيزة 95 ، جيزة 90 . وتم اجراء عمليات تحضيرية قبل الصباغة وهي : الغلي بالقلوي وعملية المرسرة الحرة باستخدام الصودا الكاوية . و تمت الصباغه بصبغة (Procion H-EXL blue dye) وهي من الصبغات النشطة زرقاء. وتمت التجارب باستخدام تركيزات مختلفة من الصبغة النشطة (2 % و 4 % و 6 %) للحصول على درجات لونية مختلفة وتحقيق الظروف المثالية للصباغة .و تم دراسة عمق لون ، خواص درجة الثبات اللونية للصبغة ضد الغسيل والاحتكاك والعرق القلوي والحامضي و كذلك الخواص الميكانيكية للاقمشة المصبوغة.

وأظهرت النتائج امكانية استخدام هذه التقنية في اجراء عملية الصباغة حيث حققت نتائج صباغة وعمق لون وخواص ثبات جيدة ، وليس لها تأثير ضار على الخواص الميكانيكية للأقمشة القطنية (المتانة والاستطالة). كما تبين أن الظروف المثلى للصباغة هى استخدام تركيز 4 % من الصبغة عند درجة حرارة 60 درجه مئويه لمدة 45 دقيقة.

و توصي الدراسة بتطبيق استخدام الاشعه تحت الحمراء كمصدر حراري في مصانع صباغة وتجهيز المنسوجات وذلك لتحقيق البعد البيئي والاقتصادي .