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A Comparative Study on Microwave Assisted Dyeing Properties of Conventional and Recycled Polyester Fabrics

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Abstract: In the literature, microwave studies are predominantly on cellulosic based fabrics and there are limited studies in microwave assisted polyester dyeing. Today, due to the interest in recycled polyester, it was decided to study conventional and microwave heating in the exhaust dyeing methods of recycled polyester and conventional polyester fabrics. The aim of the study was to determine whether microwave heating could be used to shorten dyeing process times and to obtain dyeing with sufficient colour fastness. Accordingly, two samples, 100% polyester and 62% recycled polyester 38% polyester woven fabrics, are used. The samples were dyed with 1.5% Bemacron Smart Red EE disperse dye. The colorimetric properties, colour fastnesses and tear strength of the dyed fabrics were investigated and compared with each other. Spectrophotometer measurements were evaluated that 100% polyester fabric dyed with the microwave method had a darker colour compared to the conventional method, on the other hand, there was no significant colour difference between the conventional and microwave dyeing method of the 62% recycled polyester 38% polyester woven fabric. Colour fastness test results were evaluated that all the fastness results of the recycled and conventional polyester fabrics in the microwave tests were obtained 4 and 4-5. The advantages of microwave heating over the conventional method are that the dyebath heats up in a short time and gives good colour fastnesses without any deterioration in the properties of dyed materials.

Keywords: Polyester fabric, Recycle, Dyeing, Microwave

Introduction

In textile industry, conventional polyester fiber is the most used synthetic fiber and used in global textile clothing about 60%. Polyester fiber has excellent properties, like as spinnability, durability, dyeability, good abrasion resistance and wrinkle resistance but not an environmentally friendly fiber because of reduce fossil fuels which is non-renewable material. Recycled polyester fiber is made from plastic bottles. Recycled polyester fiber production is important as it releases less CO_2 into the environment than conventional polyester fiber production, reduces oil fuel waste and overall carbon footprint (Basit et al., 2023; Qian et al., 2021).

Polyester dyeing is hard because the polyester fiber has high crystalline fiber microstructure and absense of reactive sites. Polyester is generally dyed with disperse dyes and using high temperature dyeing method which require high energy and water consumption (Syed et al., 2014). In recent years, textile sector has been looking for equivalent production methods to conventional production methods for sustainable eco-friendly production. Since textile wet processes are the processes that most pollute the environment during textile production, alternative production methods are sought for these processes. Utilizing microwave energy in textile wet processes provides sustainable environmentally friendly production by reducing energy costs and processing time (Eyuboglu, 2020).

Microwaves are high-frequency, short-wavelength electromagnetic fields that lie between radio and infrared waves on the electromagnetic spectrum. Microwave length range is between 1 cm and 1 m, microwave frequency range is between 30 GHz and 300 MHz. Microwaves interact with materials in three ways: reflection, absorption and transmission. When the material absorbs the microwave energy, microwaves reach all the particles of the material at the same time uniformly and microwaves heat the material. For this reason, microwave heating provides faster, more effective and homogeneous heating than conventional heating (Öner et al., 2013; Eyupoglu, 2020). In the textile industry, microwave energy is used not only for drying but also for microwave dyeing, fixation of printed fabrics, and surface modification processes (Ozerdem et al., 2008; Kocak et al., 2015).

In the literature, there are many studies on developing different techniques, including microwave irradiation, to improve dyeing behavior of fibers. But there are limited studies in microwave assisted polyester dyeing to reduce high energy and water consumption and improve dyeing behavior. For example, Adeel et al. (2018) observed that the color strength of disperse dyed polyester fabrics improved in the microwave method application and there was no significant change on the polyester fabric properties. Elshemy et al. (2017) studied that the effects of microwave dyeing process parameters (dye concentration, temperature and time) on the color yield, fastness, strength and elongation properties of dyed fabrics for the microwave dyeing process applied to different polyester woven fabrics. As a result of the microwave dyeing process, uniform dyeing and good fastness properties were observed on the polyester woven fabrics. El Apasery et al. (2017) observed that polyester fabrics disperse dyed with ultrasound dyeing method and microwave dyeing method have good fastness properties and energy savings are achieved as the process takes place at lower temperature. Likewise, Syed et al. (2014); Oner et al. (2013); Al Mousawi et al. (2013); Kim et al. (2003) observed that polyester fabrics disperse dyed with microwave irradiation energy method showed good fastness, uniform dyeing, low energy, short time.

In this study, different from the literature, due to the interest in recycled polyester, dyeing properties of recycled polyester woven fabrics according to conventional exhaust dyeing method and microwave irradiation energy dyeing method were investigated. The aim of the study was to determine the usability of microwave energy to shorten dyeing process time and to obtain uniform dyeing with sufficient colour fastness for recycled polyester woven fabrics.

Method

For the study, two different samples, 100% polyester (100% PES) and 62% recycled polyester 38% polyester (62% r-PES 38% PES) woven fabrics, were used. Table 1 shows the structural properties of woven fabrics. Woven fabrics were produced by using polyester yarns in warp direction, polyester and recycled polyester yarns in weft direction.

Table 1. Woven fabrics properties

Fabric Name	PES	Recycled PES
Fabric Composition (%)	100% PES	62% r-PES 38% PES
Warp Yarn	75den/36f Polyester	75den/36f Polyester
Weft Yarn	150den/144f Polyester	150den/144f Recycled Polyester
Warp Density (yarn/cm)	40	40
Weft Density (yarn/cm)	32	32
Weave	Twill	Twill
Weight (g/m^2)	120	120

The samples were dyed with 1,5% Bemacron Smart Red EE disperse dye according to the conventional high temperature exhaust method (HT Dyeing) (130°C, 40 minute) (dyeing diagram is seen at Figure 1.)

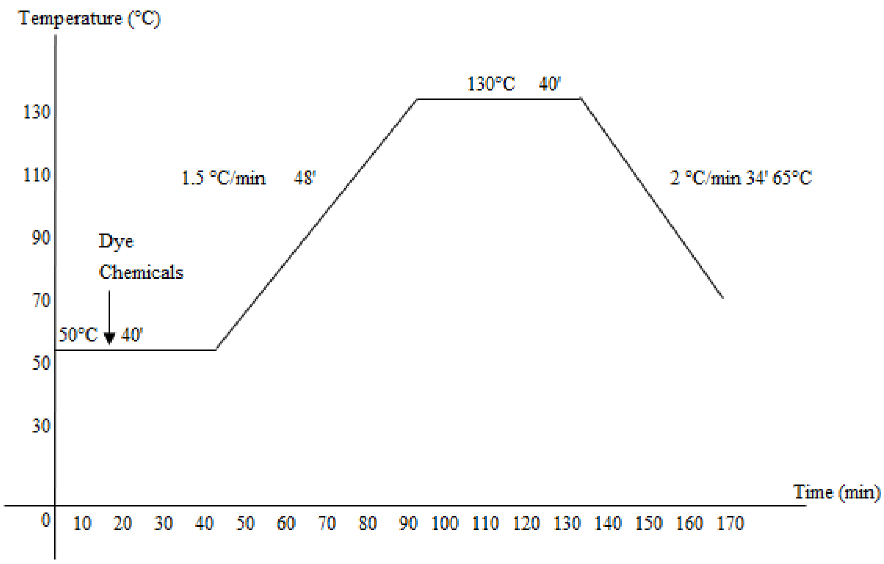

Figure 1. Conventional (HT dyeing) disperse dyeing diagram

It was inspired by the studies in the literature Kocak et al. (2015) and Oner et al. (2013) to improve the microwave assisted disperse dyeing process. Kocak et al. (2015) applied 460 W microwave energy for 3 minutes and then 120 W energy for 5 minutes in order to develop the microwave disperse dyeing process of polypropylene fibers. As a result of the pre-microwave processes, it was decided to use 480 W and 160 W microwave energy. Microwave assisted dyeings were carried out a liquor ratio of 50:1 and 480 W for 7.5 minutes and 160 W for 12.5 minutes in a microwave oven (Arcelik MD 820 model, maximum power 1200 W, 2450 MHz). Dyeing diagram is seen at Figure 2.

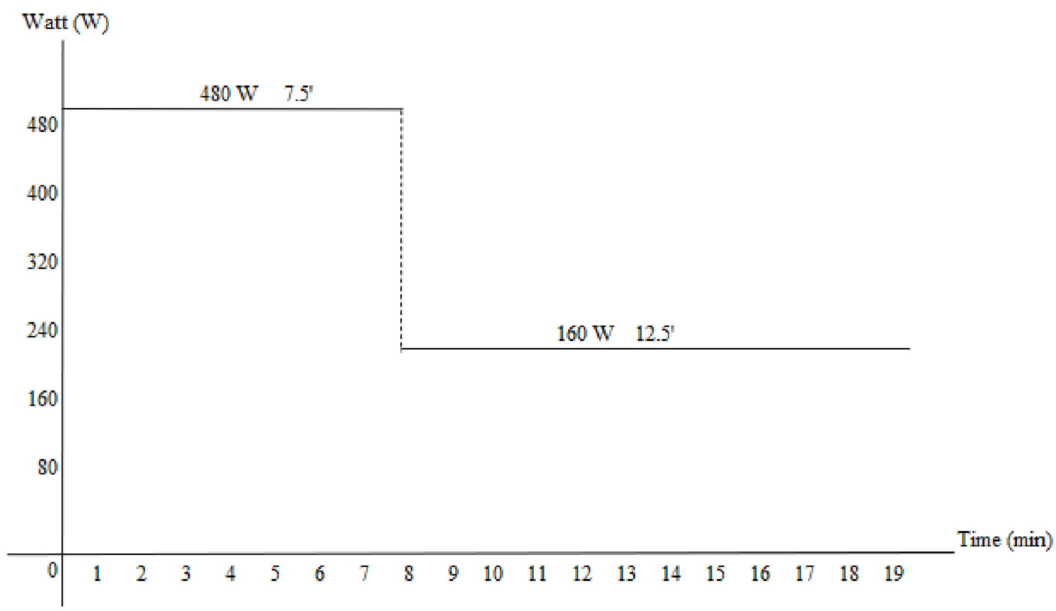

Figure 2. Microwave assisted disperse dyeing diagram

At the end of the dyeing processes, a reduction clearing process was carried out a liquor ratio of 10:1, 1 g/l sodium hydrosulfite and 2 g/l sodium hydroxide for 20 min at 80 ºC. After reduction clearing process, neutralizing with 1 g/l acetic acid for 5 min and rinsing in cold water. Dyed samples were dried at ambient temperature.

The CIELab values of fabrics were measured using a Datacolor (USA) SF600 Plus-CT spectrophotometer (D65 and 10^{o} standard observer values). TS EN ISO 13937-2 tear strength (single tear method), TS EN ISO 105 C06 colour fastness to washing, TS EN ISO 105 E01 colour fastness to water, TS EN ISO 105 E04 colour fastness to perspiration, TS EN ISO 105 X12 colour fastness to rubbing tests were determined according to ISO standards.

Results and Discussion

The colorimetric properties, fastness and tear strength (single tear method) of polyester and recycled polyester woven fabrics dyed according to conventional and microwave method were investigated comparatively. The colorimetric parameters obtained for conventional dyed and microwave dyed polyester and recycled polyester fabrics are given in Table 2. Table 2 show that the recycled polyester fabrics dyed with microwave method is slightly lighter (ΔL* = 0.01), less green (Δa* = –0.96), more yellow (Δb* = 1.21), slightly less saturated (ΔC* = –0.9) and the colour difference (ΔE*) is 0.79 compared with the recycled polyester fabric dyed with conventional method. On the other hand, the conventional polyester fabrics dyed with microwave method is darker (ΔL* = -1.61), more green (Δa* = –2.55), more yellow (Δb* = 1.23), less saturated (ΔC* = –2.5) and the colour difference (ΔE*) is 1.43 compared with the conventional polyester fabric dyed with conventional method. Commercially, ΔE* value of less than 1 indicates that the color difference is acceptable.

Table 2. CIELab test results

Fabric Name	Dyeing Method	ΔL*	Δa*	Δb*	ΔC*	ΔH*	CMC ΔE
Recycled PES	HT Dyeing (Referance)						
	Microwave Dyeing	0.01	-0.96	1.21	-0.9	1.23	0.79
PES	HT Dyeing (Referance)						
	Microwave Dyeing	-1.61	-2.55	1.23	-2.5	1.25	1.43

Table 3 presented colour fastness values to washing of conventional disperse dyed and microwave disperse dyed polyester and recycled polyester fabrics. Staining values for multifibres (acetate, cotton, polyamide, polyester, acrylic, wool) were between 4 and 4-5 and color change values were 3-4 and 4-5 (Table 3).

Table 3. Washing fastness test results

Fabric Name	Dyeing Method	Staining						Colour change
		Acetate	Cotton	Polyamide	Polyester	Acrylic	Wool	
PES	HT Dyeing	4-5	4-5	4	4-5	4-5	4-5	3-4
PES	Microwave Dyeing	4	4-5	4	4-5	4-5	4-5	4-5
Recycled PES	HT Dyeing	4-5	4-5	4	4-5	4-5	4-5	4
Recycled PES	Microwave Dyeing	4-5	4-5	4-5	4-5	4-5	4-5	4-5

Table 4 presented colour fastness values to water of conventional disperse dyed and microwave disperse dyed polyester and recycled polyester fabrics. Staining values for multifibres (acetate, cotton, polyamide, polyester, acrylic, wool) were between 4 and 4-5 and color change values were 3-4 and 4-5 (Table 4).

Table 4. Water fastness test results

Fabric Name	Dyeing Method	Staining						Colour change
		Acetate	Cotton	Polyamide	Polyester	Acrylic	Wool	
PES	HT Dyeing	4	4	4	4-5	4-5	4-5	3-4
PES	Microwave Dyeing	4-5	4-5	4-5	4-5	4-5	4-5	4
Recycled PES	HT Dyeing	4	4-5	4	4-5	4-5	4-5	4
Recycled PES	Microwave Dyeing	4-5	4-5	4-5	4-5	4-5	4-5	4-5

Table 5 and 6 presented colour fastness values to acidic and alkaline perspiration of conventional disperse dyed and microwave disperse dyed polyester and recycled polyester fabrics. Staining values for multifibres (acetate, cotton, polyamide, polyester, acrylic, wool) were between 4 and 4-5 and color change values were 4 and 4-5 (Tablo 5 and 6).

Table 5. Acidic perspiration fastness test results

Fabric Name	Dyeing Method	Staining						Colour change
		Acetate	Cotton	Polyamide	Polyester	Acrylic	Wool	
PES	HT Dyeing	4	4	4	4-5	4-5	4	4
PES	Microwave Dyeing	4-5	4-5	4-5	4-5	4-5	4-5	4
Recycled PES	HT Dyeing	4	4-5	4	4-5	4-5	4-5	4
Recycled PES	Microwave Dyeing	4-5	4-5	4-5	4-5	4-5	4-5	4-5

Table 6. Alkaline perspiration fastness test results

Fabric Name	Dyeing Method	Staining						Colour change
		Acetate	Cotton	Polyamide	Polyester	Acrylic	Wool	
PES	HT Dyeing	4	4	4	4-5	4-5	4	4
PES	Microwave Dyeing	4-5	4-5	4-5	4-5	4-5	4-5	4
Recycled PES	HT Dyeing	4	4-5	4	4-5	4-5	4	4
Recycled PES	Microwave Dyeing	4-5	4-5	4-5	4-5	4-5	4-5	4-5

Table 7 presented colour fastness values to rubbing (wet and dry) of conventional disperse dyed and microwave disperse dyed polyester and recycled polyester fabrics. Color change values were 4 and 4-5 (Table 7).

Table 7. Wet and dry rubbing fastness test results

Fabric Name	Dyeing Method	Wet	Dry
PES	HT Dyeing	4-5	4-5
PES	Microwave Dyeing	4	4
Recycled PES	HT Dyeing	4-5	4-5
Recycled PES	Microwave Dyeing	4-5	4-5

Table 8 presented tear strenght (single tear method) values of conventional disperse dyed and microwave disperse dyed polyester and recycled polyester woven fabrics. There was no significantly difference in the tear strength values (Table 8). Accordingly, it can be said that microwave irradiation energy not had a negative effect on the tearing properties of polyester and recycled polyester fabrics.

Table 8. Tear strength (single tear method) test results

Fabric Name	Dyeing Method	Warp Tear Strenght (N)
PES	HT Dyeing	37.07
PES	Microwave Dyeing	39.99
Recycled PES	HT Dyeing	28.35
Recycled PES	Microwave Dyeing	36.14

Conclusion

Advantages of microwave irradiation energy dyeing process according to high temperature conventional dyeing process in different aspects are given below:

– Uniform dyeing process is obtainable with good colouristic properties and adequate colour fastnesses without any loss tear strength. Spectrophotometer measurements were evaluated that conventional polyester fabric dyed with the microwave method had a darker colour compared to the conventional method. This indicates that the same colour can be obtained with less dyestuff concentration. On the other hand, there was no significant colour difference between the conventional and microwave dyeing method of the recycled polyester woven fabric. It is determined that microwave dyeing not have a negative effect on the colour yield.

– The dyebath heats up in a short time with microwave heating. The microwave assisted dyeing process was completed in approximately 20 minutes, while high temperature conventional dyeing process was completed in approximately 170 minutes. As a result, high level of energy and time savings were achieved.

Considering cost-effectiveness, energy-saving and time saving of the microwave assisted dyeing process method, microwave irradiation heating is promising in textile dyeing processes.

Recommendations

With this study, it has been indicated that the amount of dyestuff and the process time can be reduced in microwave dyeing. In this context, it can be studied on the reducing the amount of dyestuff in dyeing different fibers by microwave dyeing and the optimization of different textile processes such as washing, bleaching, mercerization in future studies.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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