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Efficient Dyeing Mechanism of Cotton/Polyester Blend Knitted Fabric

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Abstract: Innovations and modifications are the continuous processes of wet processing technology in clothing and textile industries. Due to inadequacy of water resources, consumer demands, other environmental and commercial issues, a lot of research works are being carried out throughout the world to develop the eco-friendly and cost effective textile dyeing mechanism. In this research, an attempt was taken to develop efficient dyeing method of widely used cotton and polyester blend knitted fabric by the simple modification of recognized two bath cotton/polyester blend dyeing process. The main goal of this study was to find out an alternative dyeing process to reduce the water consumption, process time and production cost replacing conventional dyeing process. In this regard, the pre-treatment and dyeing process of cotton/polyester blend fabric were modified and reduction-clearing process was eliminated without applying any extra wash off chemicals. The results revealed outstanding efficiency in terms of process time, water consumption and cost minimization maintaining all quality parameters as required. By applying modified process, the water consumption was reduced approximately by 26 %, power consumption and processing time by 15 %, and steam consumption by 3.6 %, thus overall production cost by 8 %. The proposed method could be applied to cotton/polyester knitted fabric dyeing regardless of construction, blend ratio, color, and shade %.

Keywords: Cotton, Polyester, Efficient dyeing, Fastness properties, Reduction clearing

Introduction

Traditional textile wet processing consumes huge volume of water during pre-treatment, dyeing, post dyeing finishing, and other rinsing processes. Typically, 1 kg of cotton/polyester blend fabric requires 120-150 liters of water for wet processing and this water volume has significant effect on production cost and ecological balance. The dyeing process is regarded as one of the most important parts of textile wet processing, which utilizes very large volume of water and energy [1-3]. Therefore, it is essential to design various techniques so as to reduce the process time, energy consumption, and production cost during entire dyeing procedures. The amount of water used in various textile wet processing mills vary depending on the equipment, process adopted, and types of fabric. Adequacy of water sources are declining alarmingly. Hence, it is worthwhile to think alternatively in order to reduce the water consumption along with power, process time, and production cost. Polyester blend cotton is one of the most widely used fabric combinations for its aesthetic use and durability. In contemporary fashion world, the consumers are not only concerned with the aesthetics, but more aware of raw materials, production process, and sustainability. In case of polyester blend cotton dyeing, reduction clearing is a widely established process done after polyester part dyeing required for the removal of surplus dyes, auxiliaries, and ease of cotton part dyeing. As reduction clearing also consumes substantial volume of water, energy, and time, it will patently be beneficial if polyester blend cotton can be dyed without reduction clearing separately. So it demands dedicated effort to be laid upon to find substitute process eliminating reduction clearing and using no other extra chemicals instead for dyeing polyester blend cotton fabric.

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In this paper, an alternative technique has been depicted instead of traditional dyeing method of cotton/polyester blend fabric by eliminating the reduction clearing process after polyester part dyeing. The usual dyeing method of cotton/polyester blend knitted fabric comprises of two bath or one bath-two step dyeing process typically [4]. A lot of works are being performed to develop the efficient dyeing process of blend fabrics [5-8]. The conservation of water sources and environment has become the issue of great importance in textile dyeing production. The global textile industry is putting tremendous effort to achieve a balance between economic development and ecological protection simultaneously. Consequently, the focus in research and development is more set on sustainable products and innovative processes. Accordingly, an attempt has been taken in this study to dye polyester blend cotton without separate reduction clearing process aiming at cost reduction and sustainability. In case of cotton/polyester blend knitted fabric, usually pre-treatment (scouring, bleaching, enzyme wash, fabric neutralization wash) is done before polyester part dyeing. Then polyester part is dyed followed by reduction clearing. Finally, cotton part is dyed and finishing processes are done as required.

In this paper, however, we have shown a different dyeing procedure replacing the earlier one that we dyed the polyester part first without pre-treatment process. After polyester part dyeing, the pre-treatment process (required for cotton part dyeing) was done followed by cotton part dyeing right away. By this simple modification we could skip the reduction clearing process reducing the process time, energy,

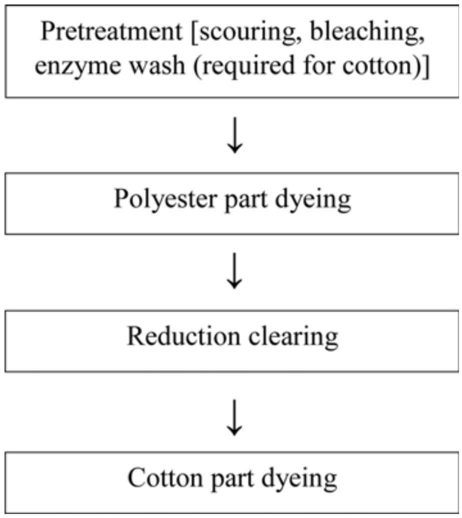


Figure 1. Traditional dyeing process flowchart of cotton/polyester blend fabric.

water consumption, chemicals, and production cost confirming all quality parameters perfect.

Dyeing of Cotton/Polyester Blend Knitted Fabric by Traditional Process

The sequential processes of dyeing of cotton/polyester blend knitted fabric by traditional process as shown in Figure 1 are described briefly in below description.

Pre-treatment (Scouring, Bleaching, Enzyme Wash for Cotton)

Scouring, bleaching, and enzyme wash of cotton part were done following established traditional method. In textile industry, NaOH is widely used for scouring agent and H_2O_2 works as bleaching agent. Scouring and bleaching were done simultaneously at 110 ºC and run for 20 min. Afterward, fabric was treated by enzyme wash to reduce the hairiness and imparting smooth surface for level dyeing.

Polyester Part Dyeing Process

High temperature and high pressure (HTHP) method is the most widely granted dyeing process for polyester and polyester blend fabric. After pre-treatment processes, polyester part was dyed with the disperse dyes in acid medium keeping the pH 4-4.5 as disperse dyes are the typical choice for polyester dyeing and most of the disperse dyes used for polyester dyeing are not applicable in alkaline medium [9,10]. The required auxiliary chemicals were dispensed by injection method whereas dyestuffs mixture was linearly dosed in 18 min to the machine at room temperature. The dyeing temperature was raised to 135 ºC by average gradient of 2 ºC/min approx. and run for 45 min. Finally, dye bath was drained followed by reduction clearing.

Reduction Clearing Process

In case of polyester dyeing reduction clearing is done to remove the unfixed dyes and auxiliaries from the surface of the fabric and for the ease of cotton dyeing and subsequent processes. The typical reduction clearing recipe for medium to dark shade comprises reducing agent - 2 g/*l*, acetic acid - 0.25 g/*l*, temperature – 80 ºC, run time - 30 min. For extra dark shade, reduction clearing is done twice. Typically, double reduction clearing process takes 2 h approximately.

Cotton Part Dyeing

Cotton part was dyed by the established reactive exhaust dyeing method at 60 ºC keeping pH 10-11.

Experimental

In this study, 60/40 cotton/polyester knitted fabric 30’s, 180 g/m^2 supplied by Esquire Knit Composite Ltd. (EKCL), Bangladesh was taken in consideration for the experiments. For the feasibility test initially, the mentioned fabric was dyed in small quantity as lab trial in solid black, blue, and navy color in different shade % by the widely used two bath HTHP polyester dyeing method without reduction clearing. In experiment, the polyester part of mentioned fabric was dyed first. Pre-treatment for cotton was done avoiding reduction clearing process after polyester part dyeing. Lastly cotton part was dyed. The M:L ratio for lab dyeing was 1:20. Getting the satisfactory result in lab dyeing, same fabric in 10 kg was dyed in a sample dyeing machine in red color where M:L ratio was 1:10. Dyeing shade and all quality parameters were observed flawlessly fine. To investigate the bulk dyeing feasibility, the same fabric in 600 kg was dyed in dark black color of which the coloration recipe is described broadly in Table 1. The machine used for bulk dyeing was SCLAVOS Athena. After the accomplishment of dyeing without reduction clearing, the quality parameters and feasibilities were compared with the process having reduction clearing.

Dyeing of Cotton/Polyester Blend Knitted Fabric by Modified Process

In the modified process, we illustrated that there is no necessity to do the reduction clearing process by a simple modification of two bath polyester blend cotton dyeing process. In modified process, the dyeing was done according to the sequence of Figure 2 keeping the parameters alike traditional process. It is well established that scouring and bleaching are prerequisites for cotton dyeing. As the function of reduction clearing agent is to remove the surplus dyes and auxiliaries from the surface of the fabric and ease of subsequent process, NaOH and H_2O_2 in this regard can play that role after polyester dyeing at the time of pre-treatment for cotton. It could be the reason that NaOH can act as a cleaning agent [11] and H_2O_2 can do discoloration [12], and thus removing the unfixed dyes and auxiliaries from the fabric surface. Hence the purpose of scouring, bleaching for cotton, and reduction clearing after polyester

Table 1. Bulk production recipe of modified process of 60/40 cotton/polyester blend knitted fabric dyeing (dark black color – 7 % o.w.f.)

Production process	Chemicals/dyes	Function of chemicals/dyes	Concentration	Liquor ratio
Polyester part dyeing	Setalan-DFT	Levelling agent	0.5 g/l	7.3
	Sodium acetate	Maintain pH	1.0 g/l	7.3
	Acetic acid	Maintain pH	0.7 g/l	7.3
	Taicron Red SP-2RT	Coloration	0.3851 % (o.w.f.)	6.0
	Taicron Black SP-GT	Coloration	3.0289 % (o.w.f.)	6.0
Pre-treatment of cotton part dyeing	Ablutex-AP-750 (42 % sol)	Wetting agent	2.0 g/l	6.9
	Contipon S (10 % sol)	Anti-foaming agent	2.5 g/l	6.9
	Optavon 4UD	Multi-functional	1.0 g/l	6.9
	JINTEXYECO SQ-117CA	Sequestering agent	1.0 g/l	6.9
	JINSOFECO ACN	Lubricating agent	0.75 g/l	6.9
	H_2O_2 (50 % sol)	Bleaching agent	2.8 g/l	6.9
	Caustic soda	Scouring agent	2.5 g/l	6.9
	Acetic acid	Maintain pH	1.1 g/l	6.2
	Ultrox-RJK-Liq	Peroxide killer	0.4 g/l	6.5
	Unizyme_S-20	Anti-pilling	0.6 % (o.w.f.)	6.5
Cotton part dyeing (reactive exhaust dyeing process)	ALBATEX DBC	Levelling agent	1.0 g/l	8.0
	Acetic acid	Maintain pH	0.05 g/l	8.0
	JINSOFECO ACN	Lubricating agent	2.5 g/l	8.0
	Glauber salt	Dye adsorption	70 g/l	8.0
	Remazol D Black RGB	Coloration	3.4000 %	6.0
	Remazol Navy Blue GG-133 %	Coloration	0.1860 %	6.0
	Soda ash	Dyes migration	18 g/l	8.0
Soaping-1	Acetic acid	Maintain pH	1.25 g/l	7.0
	Fistol RS	Soaping agent	1.0 g/l	7.0
Soaping-2	Fistol RS	Soaping agent	1.0 g/l	7.0
Fixing	Jingen FX-RFC-536	Fixing agent	1.20 g/l	7.0
Softening	Acetic acid	Maintain pH	0.25 g/l	8.0
	Gensoft-150 (10 % sol)	Softening agent	4.0 % (o.w.f.)	8.0

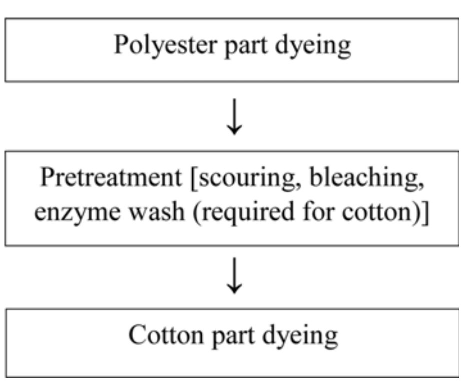


Figure 2. Modified process flow chart of cotton/polyester blend fabric.

part dyeing become fulfilled simultaneously making the entire process short, economical, and marginally ecofriendly too as no extra chemicals are used for avoiding reduction clearing.

Table 1 shows the complete production recipe of modified process of 60/40 cotton/polyester blend knitted fabric dyeing for dark black color. The dyes and chemicals used in this study were the same products that are used for polyester blend cotton dyeing by the traditional process too in Esquire Knit Composite Ltd., Bangladesh. Dyes and chemicals' names are mentioned in commercial name.

Figure 3 depicts the dyeing curve of cotton and polyester blend knitted fabric in which reduction clearing process after polyester part dyeing is included. Typically, for the dark color, reduction clearing process consumes almost 2 h extra and a lot of water and energy are required too. The overall time required for this process is 927 min approximately.

Figure 4 shows the dyeing curve where polyester part is dyed first and reduction clearing process is eliminated. Due to sequential modification of pretreatment and elimination of

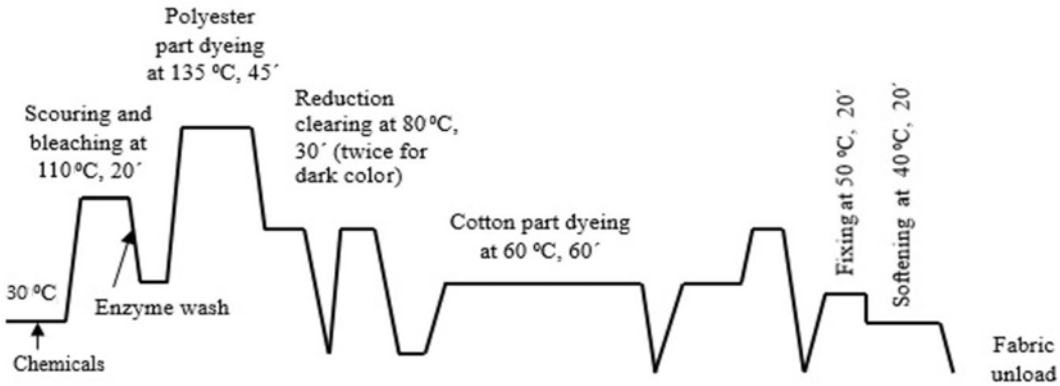


Figure 3. Dyeing curve of traditional process of cotton/polyester blend dyeing of knitted fabric.

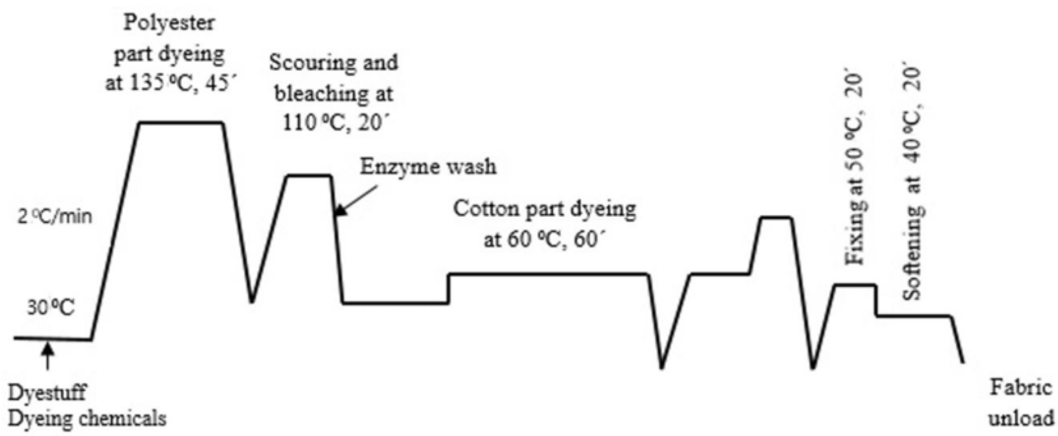


Figure 4. Dyeing curve of modified process of cotton/polyester blend dyeing of knitted fabric.

reduction clearing, the entire processing time has been shortened by 15.43 % compared to earlier process saving the water, energy, and production cost. After the modified dyeing process, the fabric sample was characterized by hand feel, color fastness to wash, rubbing, perspiration and light. To investigate the bulk dyeing comparison with the traditional one, the modified process was also scrutinized in terms of water consumption, steam consumption, power consumption, process time, and total batch cost.

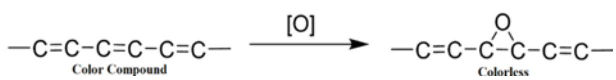
Results and Discussion

The loom state fabrics contain size, processing lubricants, and greases from harvesting, ginning, spinning, and weaving. Prior to dyeing and other finishing processes, non-cellulosic substances and other foreign materials on fabric surface have to be removed for cotton blend especially. The natural fibers and fabrics even after scouring still contain naturally occurring coloring matter [13]. For cotton or cotton blend dyeing this natural coloring matter is usually removed by bleaching. It is well established that reduction clearing is required after polyester part dyeing to remove the unfixed dyes and auxiliaries from the fabric surface [14]. We, however, tried a modified process of polyester blend cotton dyeing eliminating reduction clearing process diametrically. Accordingly, as mentioned earlier in modified process, polyester part was dyed first followed by pre-treatment (scouring, bleaching, enzyme wash) required for cotton part dyeing, and then cotton part was dyed. The key issue contributing to the avoidance of the reduction clearing after polyester part dyeing is the multifunctional effect of NaOH and H_2O_2 during the pretreatment of cotton. NaOH is a strong alkali and used as a scouring agent to increase the absorbency of cotton fiber before dyeing. It functions as a cleaning agent too in the aqueous solution by producing sodium stearate or soap ($C_{17}H_{35}COONa$) reacting with triester or triglyceride (oil or fat) present on the fabric surface as shown in equation (1). On the other hand, H_2O_2 does bleaching function to remove the natural grey color of cotton. In water, hydrogen peroxide dissociates into hydronium ion (H_3O^+) and perhydroxyl ion (HOO^-) as presented in equation (2). This HOO^- ion acts as bleaching agent and is very unstable. As illustrated in equation (3), due to the instability of perhydroxyl ion, it can be dissociated into hydroxyl ion and nascent oxygen [O] which can do discoloration. This discoloration can be explained by the breakage of chromophore due to the destruction of one or more double bond in the conjugated system of color compound caused by nascent oxygen produced during bleaching reaction as represented in equation (4). Thus, reduction clearing is done simultaneously along with scouring and bleaching.

$$\begin{array}{l} CH_2COOC_{17}H_{35} \\ CHCOOC_{17}H_{35} \\ CH_2COOC_{17}H_{35} \end{array} + 3\,NaOH_{(aq)} \longrightarrow \begin{array}{l} CH_2OH \\ CHOH \\ CH_2OH \end{array} + 3\,C_{17}H_{35}COONa \quad (1)$$

$$H_2O_2 + H_2O \longrightarrow H_3\overset{+}{O} + HOO^- \quad (2)$$

$$HOO^- \longrightarrow {}^-OH + [O] \quad (3)$$



(4)

By eliminating reduction clearing after polyester part dyeing, BOD, COD, and TOC problems that are typically generated as a result of traditional reduction clearing can also be resolved [14]. Notably, the dyestuffs (Taicron Red SP-2RT and Taicron Black SP-GT) used for polyester dyeing in this study can be termed as alkali clearable dyes because the reduction clearing process is completely eliminated and its purpose has been fulfilled by the multifunctional effect of pretreatment chemicals (NaOH, H_2O_2) used for cotton dyeing and the pretreatment such as scouring and bleaching was done simultaneously in highly alkaline medium at pH 12-13. As aforementioned, pretreatment process was done just after polyester dyeing which clearly indicates the alkali clearing ability of used disperse dyes. In other studies, azohydroxypyridone and naphthalimide based alkali clearable disperse dyes containing fluorosulfonyl group have been discussed where traditional reduction clearing process was replaced by alkali clearing process using NaOH and detergent excluding sodium hydrosulfite from the recipe. Little staining and poor wash fastness were observed although dyeing was carried out on 100 % polyester substrate in those cases [15-17]. On the other hand, in case of polyester blend cotton dyeing our modified process showed no requirement of either reduction clearing or any extra wash off chemicals assuring the dyeing properties and quality parameters. Consequently, process time and utility consumption have reduced significantly making the process economical and environment friendly. In addition, the bulk dyeing comparative result as demonstrated in Table 6 clarifies the commercial feasibility of modified process. Remarkably, the principal focus of this study has been the development of an efficient dyeing process for polyester blend cotton by strategic modification regardless of disperse dyes category, blend ratio, color, and shade %.

Table 2. Color fastness to washing and rubbing

Fastness to	Staining to	Grading (dyed with reduction clearing)	Grading (dyed without reduction clearing)
Washing	Acetate	4-5	4-5
	Cotton	4-5	4-5
	Nylon	4-5	4-5
	Polyester	4-5	4-5
	Acrylic	4-5	4-5
	Wool	4-5	4-5
Dry rubbing	Standard rubbing cloth	4-5	4-5
Wet rubbing	Standard rubbing cloth	2-3	2-3

Fabric Hand Feel

The hand of the fabric is usually defined as feel of fabric against skin. It is one of the most important fabric qualities to be ensured, as faulty fabric surface may cause inevitable irritation as clothing remains next to human skin. The experimented fabric sample's hand feel was investigated manually and found satisfactorily fine with no mentionable change compared to the sample processed traditionally.

Color Fastness to Washing and Rubbing

Table 2 shows the color fastness properties to wash, dry rubbing, and wet rubbing of dark black color dyed with and without reduction clearing process. The comparative analysis of these three fastness properties was done in this regard. From Table 2, it is evident that there is no change in fastness grading of the polyester blend cotton dyeing by conventional and modified process with and without reduction clearing, respectively. All the grades are ranged in 4-5 except wet rubbing fastness which symbolizes very good wash fastness properties accepted by almost all buyers. The wash fastness and rubbing fastness properties were measured by ISO 105-C06: A2S and ISO 105-x12, respectively.

Color Fastness to Acid and Alkali Perspiration

Table 3 represents the color fastness properties of dark black color in acid perspiration and alkali perspiration solution of polyester blend cotton knitted fabric dyeing with and without reduction clearing process. In this case the results also showed no difference in fastness grading between dyeing process with and without reduction clearing. Both dyeing processes showed the same corresponding fastness grading both in acid and alkali perspiration solution. In this occasion all the fastness grading became ranged in 4-5 except staining to nylon being graded 4 in case of acid perspiration solution, but this grading was same in both dyeing processes with and without reduction clearing. The

Table 3. Color fastness to acid and alkali perspiration

Fastness to	Staining to	Grade in acid perspiration (with reduction clearing)	Grade in acid perspiration (without reduction clearing)	Grade in alkali perspiration (with reduction clearing)	Grade in alkali perspiration (without reduction clearing)
Perspiration	Acetate	4-5	4-5	4-5	4-5
	Cotton	4-5	4-5	4-5	4-5
	Nylon	4	4	4-5	4-5
	Polyester	4-5	4-5	4-5	4-5
	Acrylic	4-5	4-5	4-5	4-5
	Wool	4-5	4-5	4-5	4-5

Table 4. Color fastness to light

Fastness to	Grade (with reduction clearing)	Grade (without reduction clearing)
Light	3-4	3-4

perspiration fastness in this circumstance was measured by ISO 105 - E04 method.

Color Fastness to Light

Table 4 shows the color fastness to light of the fabric dyed with and without reduction clearing process denoting the same grades being 3-4. The color fastness to light was carried out by ISO 105-B02 method. So, according to all fastness results, it can clearly be claimed that the modified process is patently well compatible replacing the widely used traditional polyester blend cotton dyeing method.

Color Measurement

The effect of dyeing with and without reduction clearing on the color properties were assessed by color measurement of the samples. Accordingly, the dyed shades were characterized by CMC DE value against the targeted shade and compared with the shade undergone through traditional process. The CMC values were derived by dint of a spectrophotometer (Datacolor, USA, Model – SF 600X) machine. Notably, the CMC DE value ranges from 0-1. Closer value to 0 symbolizes well shade matching. Although both (modified and old) the shades passed CMC decision but the DE values of experimented shade showed more compatibility compared to old process meaning well exploitability of modified process as depicted in Table 5.

Comparison between Traditional and Modified Process

To compare the changes in bulk quantity dyeing between two processes, the same fabric (60/40 cotton/polyester knitted fabric 30's, 180 g/m^2) in 600 kg was dyed in the same color (dark black) by the modified process excluding reduction clearing and compared with the fabric dyed earlier by the traditional process in the same machine with the same particulars and parameters. The observations between two processes are mentioned in Table 6.

Table 6 shows the comparison in terms of water consumption, steam consumption, power consumption, processing

Table 5. Color values of dyed shade

Process	Observer	CMC DE	DL*	Da*	Db*	DC*	DH*	CMC decision
Traditional (with reduction clearing)	D65 10^o	0.84	-0.84	-0.11	-0.05	-0.07	-0.10	Pass
Modified (without reduction clearing)	D65 10^o	0.40	-0.37	-0.05	0.12	-0.09	0.09	Pass

DL*: lightness difference between sample and standard (negative value=darkness, positive value=lightness), Da*: red-greenness difference between sample and standard (negative value=green, positive value=red), Db*: yellow-blueness difference between sample and standard (negative value=blue, positive value=yellow), DC* & DH* mean change in chroma and hue between sample and standard respectively.

Table 6. Comparison of 60/40 cotton/polyester dyeing with and without reduction clearing process

Parameters	60/40 C/P dyeing with reduction clearing	60/40 C/P dyeing without reduction clearing	Reduction % of parameters (without reduction clearing)
Water consumption (*l*)	80,704	59,864	25.82
Steam consumption (kg)	3,196.2	3,080.4	3.62
Power consumption (kWh)	254.9	215.9	15.30
Processing time (minute)	927	784	15.43
Total batch cost (BDT)	78,158	71,896	8.01

time, and total batch cost for 600 kg fabric of 60/40 cotton/polyester dyeing with and without reduction clearing process. For avoiding reduction clearing process the water consumption, steam consumption, power consumption, process time, and total batch cost have been reduced by 25.82 %, 3.62 %, 15.30 %, 15.43 %, 8.01 %, respectively, depicting a considerable financial save. The total batch cost is expressed in Bangladeshi currency (BDT). The costing is based on the actual prices of materials used, overhead cost, utility consumption, process time, and related issues obtained from EKCL. Notably, the costing is subjected to vary according to raw material prices, local utility expenditures, and other associated issues.

The results presented indicate that the modified process could be an exploitable substitute against traditional process of polyester blend cotton knitted fabric dyeing in order to skip the reduction clearing process after polyester part dyeing. Most of all the results revealed the same grading compared to the old process depicting the good surface cleaning and decoloration of unfixed dyes during pretreatment of cotton after polyester part dyeing fulfilling the purpose of reduction clearing also. Hence, reduction clearing process could be avoided without using any other extra chemicals making the dyeing process short and sustainable in case of any polyester blend cotton knitted fabric dyeing.

Conclusion

In this study, it is evident that an alternative process has been devised by simple modification of intensively used HTHP polyester blend cotton dyeing method that polyester blend cotton knitted fabric regardless of any ratio, construction, and color can be well dyed without reduction clearing process keeping all the quality parameters maintained. The main objective of this study was to find out an efficient dyeing process of polyester blend cotton knitted fabric. The results showed very good color fastness properties to wash, dry rubbing, wet rubbing, acid perspiration, alkali perspiration, and light. Fabric surface and hand feel were also found well acceptable. Moreover, neither the shade matching was cumbersome nor any restriction was observed during the entire dyeing process. As cotton is a cellulosic fiber, the mentioned modified process would also be well applicable to other cellulosic fiber (viz. viscose rayon, linen, modal, etc.) blend with polyester. The results showed that by adopting this method in bulk production, a factory can get a benefit reducing water consumption, steam consumption, power consumption and processing time, thus reducing the production cost substantially. We believe that the studied modified process would also be applicable for polyester blend cellulosic woven fabric. So this dyeing method can be very exploitable and cost effective for a textile dyeing industry.

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