

Comparison of direct and reactive dyeing in terms of technical, economic and ecological perspectives

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Today, the concept of sustainable and environmentally friendly production has gained great importance. Currently, reactive dyes are predominantly used in the dyeing of cotton fabrics. However, when direct dyes are used in light and medium shades, they have the potential to provide significant advantages in terms of wastewater load since they require little to no alkali and have very low salt requirements. In this study, 100% cotton single jersey fabric samples were dyed with yellow, red and blue direct dyes belonging to trichromatic combination at 4 different depths, 0.5-1-2-3%, and the obtained colour yield values were statistically analysed. Then, fastness tests were conducted on the fabric samples. In the second stage of the study, the colours of the fabric samples dyed with direct dyes at 1% depth were taken as reference and these colours were matched with reactive dyes. Then, the same colour obtained by direct dyeing and reactive dyeing was compared with each other in terms of technical (colour, washing, rubbing, water, perspiration and light fastness values), economic (chemical, energy and water consumption for 1 kg fabric dyeing (including after-treatments)) and ecological (chemical oxygen demand, biological oxygen demand and pH value of the dyeing wastewater) aspects.

Keywords: Direct, Dye, Economic, Fastness, Reactive

1 Introduction

Today, the concept of sustainable and environmentally friendly production has gained great importance. Currently, reactive dyes are mainly used in the dyeing of cotton fabrics. As it is known, reactive dyes, unlike all other dye classes, have reactive groups that provide covalent bonding by chemical reaction with the fibre. The functional groups that can react with the reactive group are hydroxyl groups in cellulose. Since water is also present in the dyeing environment, the reactive group of the dye can react not only with the hydroxyl groups of cellulose macromolecules, but also with the hydroxyl groups of water (hydrolysis), and the reactive group that has reacted with water (hydrolysed) loses its ability to react with cellulose. The degree of fixation of monofunctional reactive dyes containing a single reactive group in its structure is around 60%, i.e. 40% of the dye used is hydrolysed with water by not participating in the dyeing process. As a solution to this problem, reactive dyes with two reactive groups (bifunctional) were developed in the mid-1980s, allowing for high fixation values. In bifunctional dyes, the percentage of dye bound to fibre

has increased to 84 %¹⁻³. However, regardless of the conditions, it is not possible to ensure that all of the reactive dyes react with the fibre and therefore the wastewater contains dead dye called hydrolysate. Additionally, high amounts of salt and alkali are required for reactive dyeing to occur. This causes the pH of the effluent to have a high alkalinity and requires a neutralisation process. On the other hand, since the affinity of reactive dyes to fibres is weak, very high amounts such as 50-100 g/L of salt should be used in dyeing. For all these reasons, studies have been carried out in recent years on the cationisation of cotton to increase the yield and reduce the use of salt in reactive dyeing. However, the environmental effects of the chemicals used in the cationisation process should also be taken into consideration. In fact, direct dyes, which have high affinity for cotton due to their larger molecules, have been known for a long time.

Direct dyes can be represented by the general formula $D(SO_3Na)_n$ ($n=1-5$). Other substituents in their structure include hydroxyl, amino, amido, etc.⁴ More than 75% of all direct dyes are non-metallised azo structures and all shades of colour are available in this group. The vast majority of these are diazo species in colours ranging from brighter yellow to blue, or polyazo species, which predominate in darker greens,

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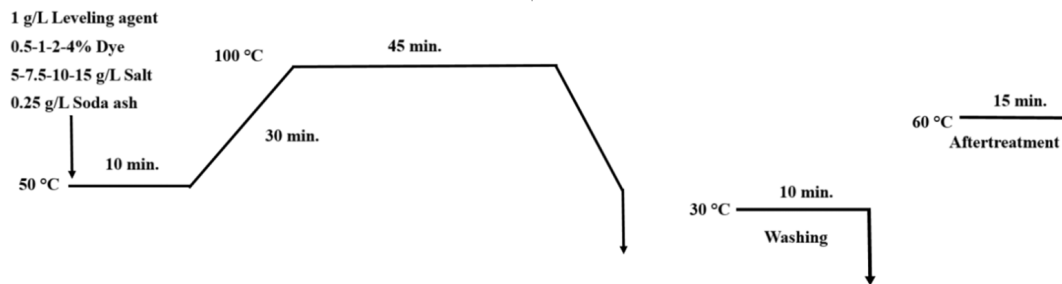


Fig. 1 — Direct dyeing recipe and dyeing and after treatment graphs

browns, greys and blacks. Approximately 50 % of all direct dyes are diazo⁵. However, since these dyes do not have the ability to make covalent bonds to fibres and they can only bond to fibres by secondary attraction forces and H bridges, their wet fastness is low, especially in dark colours⁶. However, when used in light and medium shades, they have the potential to provide significant advantages in terms of wastewater load since they require little to no alkali and their salt requirements are very low. In addition, since the dye remaining in the liquor at the end of dyeing in direct dyeing is in the same form as at the beginning, the wastewater can be reused in the next batch, that is, it has the potential to work in a standing bath. This means water, chemical and dye saving and is an important advantage.

In our previous study⁷, the production of a yellow color using direct and reactive dyes was compared in terms of colour and fastness. However, to compare the two dyeing processes and reach definitive conclusions, colour and fastness properties alone are not sufficient. The technical, economic, and ecological dimensions of the subject must be considered. Therefore, in this study, 100% cotton single jersey fabric samples were dyed with yellow, red and blue direct dyes of trichromy at 4 different depths (0.5-1-2-3%) and the colour yield values obtained were statistically analysed using Minitab 19 software. Then, washing, rubbing, water, perspiration (acidic and alkali) and light fastness tests were conducted on the fabric samples. In the second stage of the study, the colour of the fabric sample dyed with direct dye at 1% depth was taken as reference and this colour was matched with reactive dye. Then, the same colour obtained by direct dyeing and reactive dyeing was compared with each other in terms of technical (colour, washing, rubbing, water, perspiration and light fastness values), economic (chemical, energy and water consumption for 1 kg fabric dyeing (including after-treatments)) and ecological (chemical oxygen demand, biological oxygen demand and pH value of the dyeing wastewater) aspects. A review of

the literature reveals that the advantages and disadvantages of direct and reactive dyeing are already well known. However, the aim of this study is to identify the technical, economic, and ecological advantages and disadvantages of achieving the same color using direct or reactive dyes. Since no studies have been conducted directly using this approach in the literature, it is believed that this study will contribute to the literature.

2 Materials and Methods

In this study, 100% cotton single jersey fabric samples were dyed with Dyedirect Yellow PG, Dyedirect Red 3BL and Dyedirect Blue R (Setaş) dyes at 4 different depths (0.5-1-2-3%). After dyeing, the samples were aftertreated with 2% cationic fixing agent at pH 4.5 (with acetic acid) at 60 °C for 15 min. The dyeing recipe and dyeing and after treatment graphs are given in Fig. 1.

Then the colour yield (K/S) values of the fabric samples were measured by spectrophotometer. The colour yield values obtained were statistically analysed using Minitab 19 software. Variance analysis was carried out according to General Linear Model. The effect of 2 factors namely dye and dyeing depth was analysed. For the analysis of the dyeing depth, main effects plots were drawn to graphically summarize the results. Then, washing, rubbing, water, perspiration (acidic and alkali) and light fastness tests were conducted on the fabric samples.

In the second stage of the study, the colour of the fabric sample dyed with direct dye at 1% depth was taken as reference and this colour was matched with reactive dye. Table 1 shows the dyeing recipes used to match the colour obtained with 1% direct dye with reactive dye.

Figure 2 shows the dyeing and after treatment graphs of reactive dyes

Then the same colour obtained by direct and reactive dyeing was compared with each other in terms of following aspects:

- technical (colour, washing, rubbing, water, perspiration and light fastness values),
- economic (chemical, energy and water consumption for dyeing 1 kg of fabric (including after-treatments)) and
- ecological (chemical oxygen demand, biological oxygen demand and pH value of the dyeing wastewater)

Table 1 — Reactive dyeing recipes

Yellow	Red	Blue
0.2 g/L Leveling agent	0.2 g/L Leveling agent	0.2 g/L Leveling agent
1.7% Jakofix Yellow	0.3% Jakofix Yellow ME4GL	0.5% Jakofix Red ME4BL
0.3% Jakazol Golden Yellow	0.7% Jakazol Red ME4BL	0.6% Jakazol Navy
60 g/L NaCl	1.3% Jakazol Red MEGF	0.8% Jakazol Admiral Blue DS
14 g/L Soda ash	60 g/L NaCl	110 g/L Na ₂ SO ₄ .10H ₂ O
	14 g/L Soda ash	12 g/L Soda ash

Table 2 — Analysis of variance results for K/S values of dyeing at different depths

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Dye	2	53,575	26,788	41,83	0,000
Dyeing Depth, %	3	762,280	254,093	396,75	0,000
Error	30	19,213	0,640		
Total	35	835,069			

Table 3 — Tukey analysis results for K/S values of dyeing with different dyes

Dye	N	Mean	Grouping
Direct Yellow PG	12	14,7209	A
Direct Blue R	12	14,1190	A
Direct Red 3BL	12	11,8852	B

Table 4 — Tukey analysis results for the K/S values of the dyeings made at different depths

Dyeing Depth, %	N	Mean	Grouping
3,0	9	18,4760	A
2,0	9	17,2257	B
1,0	9	11,6214	C
0,5	9	6,9770	D

In order to determine the colour yield (K/S) after dyeing, %R (reflectance) values of the fabric samples were measured using a spectrophotometer (D65/10°) in the spectral region of 400-700 nm and at the maximum absorption (minimum remission) wavelength. According to the Kubelka/Munk formula, K/S values were calculated as follows;

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

where R is the Reflectance value at the maximum absorption wavelength, K is the Absorption coefficient, and S is the Scattering coefficient

Washing, rubbing, water, perspiration and light fastness tests were conducted on the samples according to TS EN-ISO 105 C06(at 40 °C according to AIM program)⁸, TS EN- ISO 105-X12⁹, TS EN- ISO 105-E01¹⁰, TS EN- ISO 105 E04¹¹ and TS EN- ISO 105 BO2¹² standards, respectively.

Chemical oxygen demand (COD) analysis with "SM 5220:B Open Reflux -Titrimetric Method¹³" and biological oxygen demand (BOD) analysis with "BOD(5) method according to TS 4957-1 EN 1899-1 Water Quality - Determination of Biochemical Oxygen Demand (BOD_(n)) after 5 days¹⁴" were performed for direct and reactive dyeing wastewater. In addition, pH values of wastewater samples were measured by a pH meter

3 Results and Discussion

The results of the analysis of variance for the colour yield (K/S) values of the dyeings made with direct dyes at different depths are given in Table 2.

When Table 2 is examined, it is seen that there is a statistically significant difference (p<0.05) between the colour yield values of the dyeings made with different dyes and at different depths. Tukey analysis was also performed to see the source of the difference and the results are given in Table 3 and 4.

When Table 3 is examined, it is seen that the colour yields of yellow and blue dyes at the same

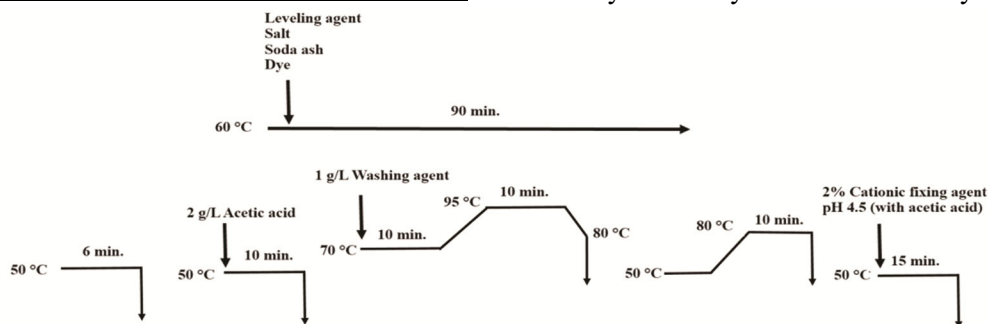


Fig. 2 — Reactive dyeing and after treatment graphs\

dyeing depth are close to each other, whereas the colour yield of red dye is slightly lower. When Table 4 is analysed, it is seen that the differences between all dyeing depths are statistically significant (all of them are in different groups). These results are clearly seen from the Interaction Plot for Colour Yield given in Fig. 3.

When Fig. 3 is examined, as expected, it is understood that the colour yield value obtained increases as the dyeing depth increases from 0.5% to 3%, i.e. the colour becomes darker. However, the colour yield increases after a depth of 2%. Photographs of the fabric samples are given in Fig. 4.

The results of washing, rubbing, water and perspiration fastness tests of fabric samples are given in Tables 5-8.

When Tables 5-8 are analysed, it is possible to say that the washing, rubbing, water and perspiration fastness values of the samples dyed with direct dyes up to 2% depth are generally at very good levels, and

when the dyeing depth increases to 3%, the fastness values decrease and reach to medium level. This situation reveals that direct dyes have a potential for use in light and medium shades.

In the second stage of the study, the colour of the fabric sample dyed with direct dye at 1% depth was taken as reference and this colour was matched with reactive dye. Photographs of the fabric samples are given in Fig. 5.

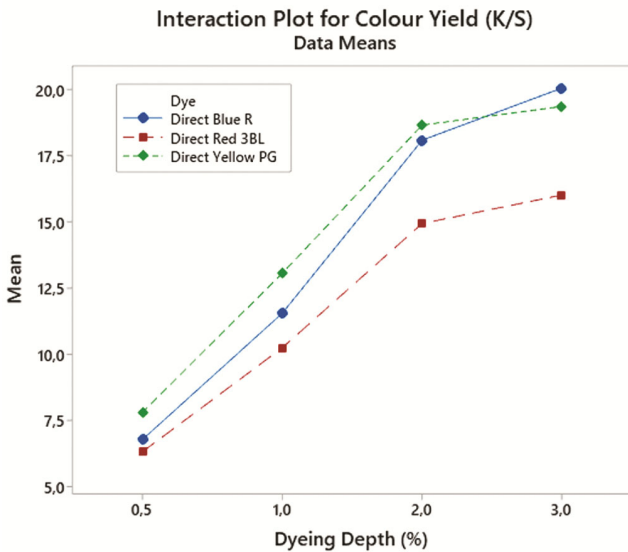


Fig. 3 — Interaction Plot for Colour Yield

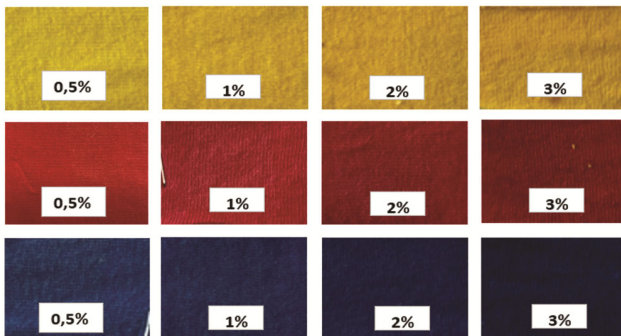


Fig. 4 — Photographs of fabrics dyed at different depths

Table 5 — Washing and rubbing fastness results of fabrics dyed with direct dyes at different depths

Fastness	Depth, %	Rubbing		Washing					
		Dry	Wet	WO	PAC	PES	PA	CO	CA
Yellow	0.5	4/5	4/5	4/5	4/5	4/5	4	3/4	4/5
	1	4/5	3	4/5	4/5	4/5	4	3	4/5
	2	4	3	4	4	4/5	3/4	3	4
	3	4	3	4/5	4	4/5	3/4	2	4/5
Red	0.5	4/5	3/4	4/5	4/5	4/5	4/5	4/5	4/5
	1	4/5	3/4	4/5	4/5	4/5	4/5	4/5	4/5
	2	4/5	3	4/5	4/5	4/5	4/5	4	4/5
	3	4	3	4/5	4/5	4/5	4/5	4	4/5
Blue	0.5	4/5	4	4/5	4/5	4/5	4/5	4/5	4/5
	1	4/5	3/4	4/5	4/5	4/5	4/5	4/5	4/5
	2	4	3	4/5	4/5	4/5	4/5	4/5	4/5
	3	4	3	4	4	4/5	4	4	4/5

Table 6 — Water fastness results of fabrics dyed with direct dyes at different depths

Fastness	Depth, %	WO	PAC	PES	PA	CO	CA
Yellow	0.5	4/5	4/5	4/5	4/5	4	4/5
	1	4/5	4/5	4/5	4/5	4	4/5
	2	4/5	4/5	4/5	4/5	4	4/5
	3	4	4	4	3/4	3	4
Red	0.5	4/5	4/5	4/5	4/5	4/5	4/5
	1	4/5	4/5	4/5	4/5	4	4/5
	2	4/5	4/5	4/5	4	4	4/5
	3	4/5	4/5	4/5	4	3/4	4/5
Blue	0.5	4/5	4/5	4/5	4/5	4/5	4/5
	1	4/5	4/5	4/5	3/4	3	4/5
	2	4	3	3	2	2	3
	3	3	3	3	2	2	2

Table 7 — Acidic perspiration fastness results of fabrics dyed with direct dyes at different depths

Fastness	Depth, %	WO	PAC	PES	PA	CO	CA
Yellow	0.5	4/5	4/5	4/5	4/5	4	4/5
	1	4/5	4/5	4/5	4/5	4	4/5
	2	4/5	4/5	4/5	4	3	4/5
	3	4/5	4/5	4/5	4	3	4/5
Red	0.5	4/5	4/5	4/5	4/5	4/5	4/5
	1	4/5	4/5	4/5	4/5	4/5	4/5
	2	4/5	4/5	4/5	4/5	4/5	4/5
	3	4/5	4/5	4/5	4/5	4	4/5
Blue	0.5	4/5	4/5	4/5	4/5	4/5	4/5
	1	4/5	4/5	4/5	4/5	4/5	4/5
	2	4/5	4/5	4/5	4	4	4/5
	3	4/5	4/5	4/5	4	3	4/5

As can be seen from Fig. 5, the colours of the dyeings made with direct and reactive dyes are quite similar. The aim is not to achieve an exact colour match, but to compare the technical, economic and ecological aspects of obtaining similar colours with direct and reactive dyes.

Rubbing and light fastness values of fabric samples dyed with direct and reactive dyes in the same colour are given in Table 9. The results of the washing, perspiration, and water fastness tests on the samples are presented in Table 10.

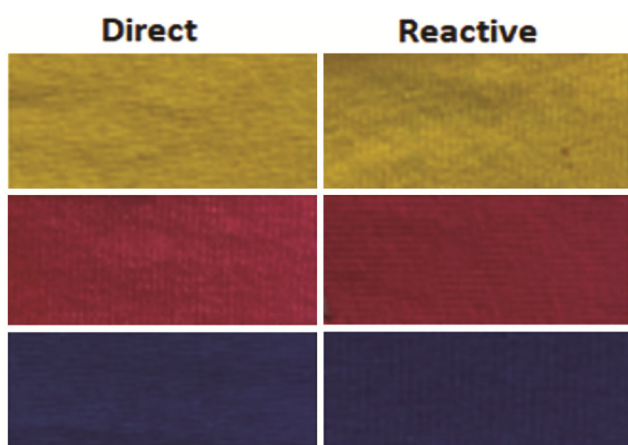


Fig. 5 — Photographs of fabrics dyed in the same colour with direct and reactive dyes

When Tables 9 and 10 are examined, it is seen that if direct dyes are used instead of reactive dyes in light colours such as 1%, there will be no problem in terms of fastness and even better results can be obtained in terms of perspiration fastness.

Table 8 — Alkali perspiration fastness results of fabrics dyed with direct dyes at different depths

Fastness	Depth, %	WO	PAC	PES	PA	CO	CA
Yellow	0.5	4/5	4/5	4/5	4/5	4	4/5
	1	4/5	4/5	4/5	4	4	4/5
	2	4/5	4/5	4/5	4	4	4/5
	3	4/5	4/5	4/5	4	4	4/5
Red	0.5	4/5	4/5	4/5	4/5	4/5	4/5
	1	4/5	4/5	4/5	4/5	4/5	4/5
	2	4/5	4/5	4/5	4/5	4/5	4/5
	3	4/5	4/5	4/5	4/5	4	4/5
Blue	0.5	4/5	4/5	4/5	4/5	4/5	4/5
	1	4/5	4/5	4/5	4/5	4/5	4/5
	2	4/5	4/5	4/5	4/5	4	4/5
	3	3	3	4	3/4	3	4/5

Table 9 — Rubbing and light fastness results of fabrics dyed in the same colour with direct and reactive dyes

Colour	Dye	Rubbing		Light
		Dry	Wet	
Yellow	Direct	4/5	3	7
	Reactive	4/5	4	7
Red	Direct	4/5	3/4	3
	Reactive	4/5	4	4
Blue	Direct	4/5	3/4	3/4
	Reactive	4/5	3/4	4

Table 10 — Washing, perspiration and water fastness results of fabrics dyed in the same colour with direct and reactive dyes

Colour	Dye	Fastness	WO	PAC	PES	PA	CO	CA
Yellow	Direct	Washing	4/5	4/5	4/5	4	3	4/5
	Reactive		4/5	4/5	4/5	4/5	4/5	4/5
	Direct	Water	4/5	4/5	4/5	4/5	4	4/5
	Reactive		4/5	4	4	3/4	3/4	3/4
	Direct	Acidic Perspiration	4/5	4/5	4/5	4/5	4	4/5
	Reactive		4/5	4/5	4/5	4	4	4/5
	Direct	Alkali Perspiration	4/5	4/5	4/5	4	4	4/5
	Reactive		4/5	4/5	4/5	4	4	4/5
	Direct	Washing	4/5	4/5	4/5	4/5	4/5	4/5
	Reactive		4/5	4/5	4/5	4/5	4/5	4/5
	Direct	Water	4/5	4/5	4/5	4/5	4	4/5
	Reactive		4/5	4	4	4	4	4
Red	Direct	Acidic Perspiration	4/5	4/5	4/5	4/5	4/5	4/5
	Reactive		4/5	4	4/5	4	3	4/5
	Direct	Alkali Perspiration	4/5	4/5	4/5	4/5	4/5	4/5
	Reactive		4/5	4	4/5	4	3	4/5
	Direct	Washing	4/5	4/5	4/5	4/5	4/5	4/5
	Reactive		4/5	4/5	4/5	4/5	4	4/5
Direct	Water	4/5	4/5	4/5	4/5	3/4	3	4/5
Reactive		4/5	4/5	4	3/4	3/4	3/4	4
Blue	Direct	Acidic Perspiration	4/5	4/5	4/5	4/5	4/5	4/5
	Reactive		4/5	4/5	4	3	3/4	4/5
	Direct	Alkali Perspiration	4/5	4/5	4/5	4/5	4/5	4/5
	Reactive		4/5	4/5	4/5	3/4	3/4	4

Table 11 — Cost comparison for direct or reactive dyeing to obtain the same colour

Cost Item	Yellow		Red		Blue	
	Direct	Reactive	Direct	Reactive	Direct	Reactive
Dye, \$	0.048	0.068	0.048	0.089	0.051	0.177
Auxiliary, \$	1.703	3.030	1.703	2.883	1.701	5.894
Water, \$	0.004	0.007	0.004	0.007	0.004	0.007
Electricity, \$	0.018	0.035	0.018	0.035	0.018	0.035
Steam, \$	0.027	0.037	0.027	0.037	0.027	0.037
Total Cost, \$	1.8	3.2	1.8	3.1	1.8	6.2

Table 12 — Analysis results of wastewater for red colour dyeing with direct and reactive dyes

Dyeing	COD, mg O ₂ /L	BOD, mg/L	Alkalinity, pH
Direct	481	175	8.91
Reactive	1469	530	10.46

The cost comparison for direct or reactive dyeing (including washing steps) for the same colour is given in Table 11.

When the cost items related to direct and reactive dyeing are analysed, the cost of auxiliaries (leveling agent, salt, soda ash, fixing agent, washing agent, acetic acid) is 40-70% higher in reactive dyeing than in direct dyeing since higher amounts of salt and soda ash are used and also washing agent for soaping and acetic acid for neutralization are necessary in case of reactive dyeing. Dye cost is also 30-70% lower when direct dyes are used. On the other hand, while 2 rinsing steps after dyeing are sufficient in direct dyeing, at least 5 rinsing steps are required in reactive dyeing. Therefore, water consumption and related costs are 45% lower in enzymatic colouring. The total time for direct dyeing is significantly lower than that for reactive dyeing, resulting in higher unit machine utilisation efficiency and lower electricity costs (50 %) and steam costs (25 %). As a matter of fact, the cost of electricity and natural gas in enzymatic dyeing is 75% lower and 60% lower than in reactive dyeing, especially in red colour, where dyeing is done at room temperature. When the total costs of dyeing are compared, the cost of direct dyeing is 40-70% lower than that of reactive dyeing. These results indicate that direct dyeing is an environmentally friendly process that enables lower-cost dyeing in a shorter time by consuming less water and energy.

Chemical oxygen demand, biological oxygen demand and pH analysis were performed on the effluents of red coloured dyeings in order to compare the environmental loads caused by the dye bath effluents when the same colour is obtained by direct or reactive dyeing and the results are presented in Table 12.

Chemical oxygen demand (COD) is one of the most important parameters used to determine the degree of pollution in domestic and, especially, industrial wastewater. Unlike biological oxygen demand (BOD), COD is based on the oxidation of organic matter through redox reactions rather than biochemical reactions^{15,16}. BOD represents the amount of oxygen consumed by aerobic bacteria to decompose organic matter within a given time period (5 days) and at a given temperature (20 °C)^{16,17}. When the values presented in Table 10 are examined, it can be concluded that the amount of organic matter in wastewater from reactive dyeing is significantly higher than that in direct dyeing. Since the same amount of leveling agent is used in both reactive and direct dyeing, there is no difference in this regard. However, the same colour could be achieved with 2–2.5% reactive dye, whereas only 1% dye is required in direct dyeing. Therefore, higher COD and BOD values in reactive dyeing are expected.

In addition, the pH value of the wastewater was 8.91 in direct dyeing, while it was 10.46 in reactive dyeing. This is because reactive dyeing requires a high amount of alkali for fixation, whereas direct dyeing uses only a small amount of alkali to ensure uniform dyeing. Thus, the high alkalinity observed in reactive dyeing wastewater is avoided in direct dyeing. It is well known that very high pH values (greater than 9.5) are unsuitable for most aquatic organisms. Therefore, if wastewater is highly alkaline, pH adjustment should be performed before discharge or biological treatment¹⁸. From this perspective, wastewater from direct dyeing can be considered more advantageous.

Salinity is another important parameter in textile wastewater. Accordingly, it is expected that the chloride content of wastewater from reactive dyeing, in which 60 g/L sodium chloride is used for a dyeing depth of 2–2.5%, will be higher than that from direct dyeing, where 7.5 g/L salt is used.

4 Conclusion

Within the scope of this study, yellow, red, and blue direct dyes belonging to trichromy were applied at different depths, and it was observed that the washing, rubbing, water, and perspiration fastness values of samples dyed up to 2% depth were very good. Subsequently, these fastness values were compared with those obtained by matching the same colour using reactive dyes, and it was found that direct dyes can serve as an alternative to reactive dyes in light shades, such as 1%. The results indicate that both the wastewater load and the cost of dyeing can be reduced by using direct dyes instead of reactive dyes in light shades. This highlights the potential environmental benefits of the direct dyeing process, which requires significantly fewer chemicals than reactive dyeing.

Despite these positive outcomes, direct dyeing cannot universally replace reactive dyeing. It is not feasible to use direct dyes to achieve sufficient fastness in darker shades, to meet specific fastness standards, or to obtain certain vivid colours due to colouristic limitations. Nevertheless, it can be concluded that the use of direct dyes, particularly in light to medium shades, offers both economic and environmental advantages.

References

- 1 Shore J, *Soc Dyers Colour*, (1995) 189.
- 2 Tarakçıoğlu I, *Ege Univ Eng Fac Publ*, (1982).
- 3 Tarakçıoğlu I, *Tekstil & Teknik*, (1990) 80.
- 4 Aspland J R, *Text Chem Color*, 23(1991) 30.
- 5 Shore J, *Soc Dyers Colour*, (1995) 152.
- 6 Yurdakul A & Atav R, *Boya Baskı Esasları (Ege Üniversitesi Tekstil ve Konfeksiyon Araştırma Uygulama Merkezi Yayını, Bornova, İzmir, Türkiye)*, (2006) 17.
- 7 Kuğu F N, Kara D, Gökçe İ & Atav R, *Proceedings, Ulusal Tekstilde Sürdürülebilirlik Sempozyumu – Geleceğin Üretim Yöntemleri, Bursa, Türkiye*, (2025).
- 8 ISO 105-C06, *Textiles-Test for colour fastness- Part C06: Color fastness to domestic and commercial laundering*, (2010).
- 9 ISO 105-X12, *Textiles-Tests for color fastness, Part X12: Color fastness to rubbing*, (1993).
- 10 ISO 105-E01 *Textiles-Tests for color fastness, Part E01: Color fastness to water*, (2013).
- 11 ISO 105-E04 *Textiles-Tests for color fastness, Part E04: Color fastness to perspiration*, (1994).
- 12 ISO 105-B02, *Textiles-Tests for color fastness, Part B02: Color fastness to artificial light*, (1994).
- 13 APHA–AWWA–WPCF 5220 B-open reflux method (SM-OR)
- 14 TS 4957-1 EN 1899-1. *Water quality- Determination of biochemical oxygen demand after n days (BODn)- Part 1: Dilution and seeding method with allithiourea addition*, (2002).
- 15 Henze M, Loosdrecht M C M, Ekama G A & Brdjanovic D, *IWA Publishing, Cambridge University Press*, (2008).
- 16 Wilhelm FM, *Encyclopedia of Inland Waters, Academic Press*, (2009) 110.
- 17 Atav R, Buğdaycı B, Bozkurt Ö, Yıldız A, Güneş E & Yakın İ, *Text Res J*, 92 (2022) 2980.
- 18 Güneş E & Atav R, *Book of Abstracts, 2nd International Conference on Natural Fibres (Sao Miguel Azores, Portugal)*, (2015) 121.