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Reduction Potential Effect during the Dyeing of Cotton Fabric by Vat Dye

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

Dyeing is one of the vital processes in the textile chemical processing industries. There are many useful commercial dyes available for the coloration of textile fiber substrates. Accordingly, cotton material is dyed mostly by reactive, sulphur and vat dyes due to their efficient characteristics. However, vat dye is highly appreciated in the cotton dyeing industries due to its overall fastness properties, even though it contains some limitations like insolubility, high cost, involvement of powerful chemicals. In this research work, the reduction potential of the reducing agents and the corresponding effects on the cotton fabric dyeing using vat dye is studied.

Keywords: Cotton fabric; vat dyeing; reduction potential; color strength; effluent.

1. INTRODUCTION

Cotton is considered as one of the important textile fibers. It is being utilized universally and its demand in increased day by day based on the aesthetic & comfort effects [1,2]. The dyeing on cotton fiber substrates is possible in all the way either by natural dyeing technique or by the conventional commercial dyes. Vat dye is one of the prominent category for the coloration of cellulosic textiles particularly cotton; for that annually more than 0.12 m. tons of vat dye is being utilized [3-5]. Compared to the effect of vat dyes especially with that one of anthra-quinone

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type of dye, no other dye contains that much overall benefits to the cotton materials during dyeing. In spite of all these benefits, vat dye also contains an important drawback of involving powerful chemicals due to its insolubility in water [6-10]. Hence, in order to make the vat dye soluble reducing agents are adopted to convert it from the insoluble form to the soluble (leuco vat) form. Vat dye has very high substantivity to the textile fiber substrates particularly cotton, in the soluble leuco form; and after dyeing in this state, the vat dye is oxidized to bring back the original insoluble form in the fiber substrate itself. In practice, during the application of vat dye in the conventional way, it is reduced with a powerful reducing agent like sodium hydrosulphite commercially known as hydrose ($Na_2S_2O_4$). Due to these chemical involvements such as sulphates, sulphides, thiosulphates, and sulphites; they are responsible for the generations of contaminants in the water bodies leading for pollution. In order to overcome this issue by the replacement of sodium hydroshulphite by any other mild reducing agents, number of research investigations have been carried out [11,12]. In this research work, an attempt is made to use different reducing agents like zinc metal powder, ferrous sulphate and sodium hydro sulphite in their intact form as well as in the combined form to increase the effect of vat dyeing and reducing the impact of the pollution load. The output of this work gives some considerable favorable results suitable for the textile chemical processing industries.

2. EXPERIMENTAL

2.1 Materials

Raw plain woven cotton (100%) fabric comprised of 130 – as ends/inch; 72 - as picks/inch; 36s – as warp count; and 40s – as weft count, was purchased from the commercial shop in Peelamedu, Coimbatore 641004, India. The auxiliary chemical and the main chemical involved in this study are in the grade of analytical form. The vat dye, Navinon Jade Green FFBU (CI: 59825) was obtained from the dye shop in Tiruppur, TamilNadu, India.

2.2 Methods

2.2.1 Basic treatment on raw cotton fabric

The raw cotton fabric should be given the pretreatments in order to make it suitable for the dyeing process. First, desizing process was performed to remove the natural as well the added size ingredients from the materials to be from these impurities. Then the desized cotton fabric is scoured using sodium hydroxide and sodium carbonate at boil for three hours inorder to make it absorptive by removing the hydrophoblic natural oily impurities. Finally, the cotton fabric is peroxide bleached using hydrogen peroxide to achieve a required uniformity & whiteness necessary for the effective dyeing effect [13,14].

2.2.2 Cotton fabric dyeing using vat dye

The vat dye was subjected on the pretreated cotton fabric with 2% owm concentration using the reducing agents such as hydrose (sodium hydrosulphite), zinc and ferrous sulphate in the intact form as well in the combined form [hydrose 2% owm, zinc 2% owm, ferrous sulphate 2% owm and in the different combination with the step of 0.5 upto 2.0] by the established dyeing procedure [15,16].

2.2.3 Reduction potential of vat dye bath

The DP001 type digital potentiometer (Pico) was used for measuring the reading of reduction potential given by the vat dyeing baths set with different reducing agents in the intact as well as in the combined form [hydrose 2% owm, zinc 2% owm, ferrous sulphate 2% owm and in the different combination with the step of 0.5 upto 2.0]. There were five readings taken for each reduction potential test and the average of them have noted [17,18].

2.2.4 Color strength & fastness properties of vat dyed cotton fabric

The cotton fabric was dyed with the vat dye using different reducing agents as mentioned earlier (2.2.2) and the colorimetry value was measured at the wavelength of 630 nm using the color matching spectrophotometer (Jaypak). The color measurement and their corresponding fastness property on the vat dyed cotton fabric samples were undergone by the well established technique as mentioned [19-21].

2.2.5 Fabric strength of vat dyed cotton fabric

The vat dyed cotton fabric samples were tested five times each for their strength in warp and weft way respectively using MAG Electronic Tensile Strength Tester with the specimen size of 25mm x 150mm by random sampling method [22].

2.2.6 Effluent load of the vat dye bath

The effluent parameters such as pH, TDS, total alkalinity, sulphate ion, BOD, and COD from the final residual vat dye baths were tested five times each by the established method and the average values were noted (Bureau of Indian standard IS3025) [23-26].

3. RESULTS AND DISCUSSION

3.1 Reducing Agent Combination Effect

The reduction potential and the corresponding statistical analysis for that available through the usage of combination of reducing agents (ferrous sulphate, zinc, & hydrose) in 0.5 steps upto 2.0 for the vat dyeing on cotton fabric are presented in the Tables 1a, 1b & 1c respectively. From these tables, it is observed that the reduction potential values are different for the different reducing agents. The reduction potential is maximum for the reducing agent hydrose (-0.84) followed by ferrous sulphate (-0.37) and zinc (-0.21). Accordingly, when the reducing agent combination is adopted as mentioned in these tables (Tables 1a, 1b & 1c), the reduction potential values also reflected in a sequential way. Based on this way, the hydrose and ferrous sulphate combinations show a good trend of reduction potential with more value for the increased concentration of hydrose. Next to this; the hydrose and zinc combination give a considerable reduction potential values. Finally, the zinc and ferrous sulphate combination give poor values only compared to other combinations. The statistical values of these reduction potential data from the different reducing agent combinations are also provided in these tables (Tables 1a, 1b & 1c). These statistical data confirm the effectiveness of the reducing agents in the intact as well as in the different combined forms respectively.

3.2 Reducing Agent Combination Effect for the Tensile Strength

The tensile strength of the cotton fabric both in warp and weft directions after dyeing with vat dye using the reducing agents (ferrous sulphate, zinc, & hydrose) in their intact form as well as in the combined form in the step of 0.5 till 2.0 is given in the Table 2. The tensile strength of the cotton fabric obtained after the vat dyeing using these differed reducing agents are compared with those of the hydrogen peroxide bleached fabric (HBF). The Table 2 shows that the tensile strength of the hydrogen peroxide bleached cotton fabric is 34.84 and 16.21 in the respective warp and weft directions. In comparison with these values the tensile strength of the vat dyed cotton fabric using these varied combination of reducing agents are reduced considerably with respect to the type and proportion of combination of reducing agents. Based on this context, the tensile strength is reduced more in the cotton fabric dyed with vat dye using hydrose as the reducing agent followed by ferrous sulphate and zinc. Similar to this trend, the combination of the reducing agents utilized for the vat dyeing on cotton fabric gives the corresponding reduction in the tensile strength. All the change in the tensile strength values are in the acceptable limit as evidenced by the standard deviation results respectively.

3.3 Reducing Agent Combination Effect for the Colorimetric Values and the Fastness Properties in the Vat Dyed Cotton Fabric

The colorimetric and the corresponding fastness property values of vat dyed cotton fabric performed using the reducing agents (ferrous sulphate, zinc, & hydrose) in their intact form as well as in the combined form in the step of 0.5 till 2.0 is given in the Table 3. The colorimetric data of the cotton fabric obtained after the vat dyeing using these different reducing agents show the varied results in the sequential way with respect to the power of the reducing agents. Obviously the color strength values are high for the vat dyed cotton fabric subjected with hydrose and its combination followed by the combination of hydrose and ferrous sulphate and at last by the combination of zinc and ferrous sulphate. All these values are reflected based on the reduction potential values (Tables 1a, 1b & 1c) given by the respective reducing agents in the intact as well in the combined form. According to the colorimetric values, the fastness property values are good to very good in almost all the cases except the rub fastness category, in which the wet rub fastness shows very poor values. Hence, it could be said that due to the effect of the reduction potential given by the respective reducing agents, the overall fastness property of the vat dyed cotton fabric also gives good influences.

Table 1a. Reducing agent combination (Zn + $FeSO_4$) effect

(Zn + $FeSO_4$) (% owm)	Reduction Potential (Volts) with Time (min)							Statistical Analysis				
Time (min)→	0	5	10	15	20	25	30	Mean	∑(X-Mean)	$\sum(X-Mean)^2$	$S_i^2=\sum(X-Mean)^2/N-1$	$F_{(cal)} = S_1^2*/S_2^2$	$F_{(TAB)}$
2.0 + 0.0	-0.21	-0.21	-0.23	-0.25	-0.25	-0.21	-0.20	-0.22	-3.12	9.75	1.63	7.04	4.276
1.5 + 0.5	-0.29	-0.30	-0.24	-0.20	-0.15	-0.23	-0.20	-0.23	-3.20	10.25	1.71	6.69	4.277
1.0 + 1.0	-0.40	-0.18	-0.17	-0.22	-0.18	-0.21	-0.17	-0.22	-3.05	9.29	1.55	7.38	4.275
0.5 + 1.5	-0.41	-0.28	-0.22	-0.20	-0.18	-0.14	-0.13	-0.22	-3.10	9.59	1.60	7.16	4.277
0.0 + 2.0	-0.37	-0.33	-0.28	-0.25	-0.25	-0.25	-0.25	-0.28	-3.95	15.62	2.60	4.39	4.279

Table 1b. Reducing agent combination (Hydrose + Zinc) effect

(Hydrose + Zinc (% owm)	Reduction Potential (Volts) with Time (min)							Statistical Analysis				
Time (min)→	0	5	10	15	20	25	30	Mean	∑(X-Mean)	$\sum(X-Mean)^2$	$S_i^2=\sum(X-Mean)^2/N-1$	$F_{(cal)} = S_1^2*/S_2^2$	$F_{(TAB)}$
2.0 + 0.0	-0.84	-0.82	-0.81	-0.78	-0.72	-0.54	-0.36	-0.23	-3.11	9.76	1.64	7.03	4.278
1.5 + 0.5	-0.41	-0.16	-0.25	-0.21	-0.16	-0.20	-0.15	-0.22	-3.07	9.40	1.57	7.30	4.276
1.0 + 1.0	-0.20	-0.30	-0.33	-0.28	-0.25	-0.22	-0.20	-0.26	-3.57	12.72	2.12	5.40	4.277
0.5 + 1.5	-0.17	-0.26	-0.29	-0.23	-0.26	-0.29	-0.32	-0.26	-3.65	13.29	2.22	5.16	4.275
0.0 + 2.0	-0.21	-0.21	-0.23	-0.25	-0.25	-0.21	-0.20	-0.22	-3.12	9.75	1.63	7.04	4.277

Table 1c. Reducing agent combination ((Hydrose + $FeSO_4$) effect

(Hydrose + $FeSO_4$ (% owm)	Reduction Potential (Volts) with Time (min)							Statistical Analysis				
Time (min)→	0	5	10	15	20	25	30	Mean	∑(X-Mean)	$\sum(X-Mean)^2$	$S_i^2=\sum(X-Mean)^2/N-1$	$F_{(cal)} = S_1^2*/S_2^2$	$F_{(TAB)}$
2.0 + 0.0	-0.84	-0.83	-0.81	-0.78	-0.72	-0.54	-0.36	-0.339	-4.714	22.2030	2.3582	4.8491	4.310
1.5 + 0.5	-0.4.0	-0.39	-0.36	-0.33	-0.30	-0.30	-0.29	-0.337	-4.712	22.2029	2.3578	4.8486	4.277
1.0 + 1.0	-0.69	-0.64	-0.62	-0.60	-0.54	-0.53	-0.52	-0.592	-8.282	68.5915	11.4319	4.6265	4.275
0.5 + 1.5	-0.44	-0.29	-0.28	-0.24	-0.22	-0.22	-0.21	-0.271	-3.794	14.3944	2.39907	4.7652	4.279
0.0 + 2.0	-0.37	-0.33	-0.28	-0.25	-0.25	-0.25	-0.25	-0.282	-3.952	15.6183	2.60305	4.3918	4.276

** S_1 = 11.43192067*

Table 2. Reducing agent combination effect for the tensile strength

Test values	HBF	Reducing agents (% owm)														
		(Zn + $FeSO_4$)					(Hydrose + Zinc)					(Hydrose + $FeSO_4$)				
		2.0+ 0.0	1.5+ 0.5	1.0+ 1.0	0.5+ 1.5	0.0+ 2.0	2.0+ 0.0	1.5+ 0.5	1.0+ 1.0	0.5+ 1.5	0.0+ 2.0	2.0+ 0.0	1.5+ 0.5	1.0+ 1.0	0.5+ 1.5	0.0+ 2.0
Tensile strength (Kg) (Warp)	34.84	31.9	28.9	28.8	28.9	30.2	29.4	29.8	29.1	29.8	31.9	29.4	30.1	32.5	30.3	30.2
Tensile strength (Kg) (Weft)	16.21	15.5	14.9	15.4	15.0	14.8	14.8	15.5	14.3	14.9	15.6	14.8	15.8	16.0	15.9	14.8
Standard deviation (σ) (Warp)	1.661	1.17	4.70	2.02	1.69	1.23	0.81	1.64	1.31	2.07	1.17	0.81	2.33	0.57	1.95	1.23
Standard deviation (σ) (Weft)	1.255	0.72	1.75	1.38	2.11	2.14	0.91	2.01	1.41	1.25	0.72	0.91	1.65	0.80	1.80	2.14

HBF → H_2O_2Bleached Fabric

Table 3. Reducing agent combination effect for the colorimetric values and the fastness properties in the vat dyed cotton fabric

Test values			Reducing agents (% owm)													
			(Zn + $FeSO_4$)					(Hydrose + Zinc)					(Hydrose + $FeSO_4$)				
			2.0+ 0.0	1.5+ 0.5	1.0+ 1.0	0.5+ 1.5	0.0+ 2.0	2.0+ 0.0	1.5+ 0.5	1.0+ 1.0	0.5+ 1.5	0.0+ 2.0	2.0+ 0.0	1.5+ 0.5	1.0+ 1.0	0.5+ 1.5	0.0+ 2.0
k/s at λ max 630 nm			0.53	0.30	0.41	0.3	1.4	2.55	1.93	2.17	2.23	0.53	2.55	2.31	2.53	2.41	1.42
Color strength (%)			20.5	11.6	15.8	9.9	56	100	74.5	85.0	87.2	20.5	100	90.5	99.2	94.5	55.7
Fastness Properties	Wash		5	5	5	5	4	5	5	5	5	5	5	5	5	5	4
	Light		5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
	Stain		3	3	3	3	3	4	3-4	3-4	3	3	4	3-4	3-4	3	3
	Rub	Dry	4	4	4	3-4	4	4	4	4	4	4	4	4-5	4-5	4-5	4
		Wet	2	1-2	1-2	2	2	2	2	1-2	2	2	2	2-3	2-3	2	2

Table 4. Reducing agent combination effect in the vat dye bath after dyeing

Effluent Parameters (ppm)	**Reducing agents (% owm)**														
	(Zn + $FeSO_4$)					**(Hydrose + Zinc)**					**(Hydrose + $FeSO_4$)**				
	2.0+ 0.0	**1.5+ 0.5**	**1.0+ 1.0**	**0.5+ 1.5**	**0.0+ 2.0**	**2.0+ 0.0**	**1.5+ 0.5**	**1.0+ 1.0**	**0.5+ 1.5**	**0.0+ 2.0**	**2.0+ 0.0**	**1.5+ 0.5**	**1.0+ 1.0**	**0.5+ 1.5**	**0.0+ 2.0**
pH	12.0	11.4	11.6	11.5	11.9	12.9	12.4	12.3	12.1	12.0	12.9	10.7	10.4	11.0	11.9
TDS	711	779	743	709	453	681	724	712	7329	711	681	466	389	402	453
Total Alkalinity	495	553	521	513	298	345	503	411	4872	495	345	297	257	316	298
Sulphate	684	608	648	611	596	698	692	679	693	684	698	591	567	584	596
BOD	288	262	242	256	198	462	291	318	385	288	462	192	185	238	198
COD	670	656	580	654	560	156	680	894	998	670	156	542	478	596	560

** exception*

3.4 Reducing Agent Combination Effect in the Vat Dye Bath after Dyeing

The results of effluent parameter with respect to pH, TDS, total alkalinity, sulphate, BOD and COD of vat dye bath after dyeing on cotton fabric performed using the reducing agents (ferrous sulphate, zinc, & hydrose) in their intact form as well as in the combined form in the step of 0.5 till 2.0 is given in the Table 4 above. The effluent values shown by the vat dye bath after dyeing on the cotton fabric using these different reducing agents show the varied results with respect to the power of the reducing agents and the corresponding colorimetric data. All these values of pH, TDS, total alkalinity, sulphate, BOD and COD are revealed in the vat dye bath after dyeing on cotton fabric based on the reduction potential values (Tables 1a, 1b & 1c) given by the respective reducing agents in the intact as well in the combined form. With respect to that and the colorimetric values, effluent values also give the response in some considerable way. In this regard, it would be mentioned that the effect of the reduction potential given by the respective reducing agents, the overall effluent parameters of the vat dyed cotton fabric also gives the good influences.

4. CONCLUSION

From this research work, it would be concluded that among the reducing agents, ferrous sulphate, zinc, & hydrose in their intact form as well as in the combined form in the step of 0.5 till 2.0, the hydrose and its combinations gives overall effect leading to give good reduction potential, significant maintenance of the tensile strength both in the warp and weft directions, increased colorimetric values and overall fastness property values, and the considerable decrease in the results of effluent parameters.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Lawrence Shaw H. Cotton's importance in the textile industry', Symposium, Lima, Peru; 1998.
2. Kadolph SJ, Langfold AJ. Cotton fibers, Textiles, 8th edition, Prentice- Hall; 1998.
3. Chen R. Eco-friendly dyestuffs point to the future (Chinese). China Textile and Apparel. 2007;25(6):46-47.
4. Jesse Fields M. Process of dyeing cotton fibers with indigo vat dyes. Cone Mills Corporation, Patent No. 4166717; 1979.
5. Adesanya Ibidapo T. Application of redox potentials in the selection of reducing agents for vat dyes. The Chemical Engineering Journal. 1992;49(2):73-78.
6. Chavan RB, Patil E. A review on electrochemical dyeing. Colourage Annual. 2004;51:77-88.
7. Westbrook P, Declerck K, Kiekaens P. Improving quality and reproducibility of the indigo dye process by measuring and controlling indigo and sodium dithionite concentrations. Textile Research Journal. 2003;73(12):1079-1084.
8. Epp, Diane N. The chemistry of vat dyes, Miami University, Middle town, Ohio; 1995.
9. Etters JN. pH- controlled indigo dyeing: Buffered dye baths Vs caustic dosing. American Dyestuff Reporter. 1998;87(9):15-17.
10. Zavrsnik T. Vat dyes today and tomorrow. Tekstilec (Slovenian). 2002;45(3-4):69-77.
11. Palmetto Section. The influence of vat dye particle size on colour yield and industrial wash fastnesses. Textile Chemist and Colorist. 1991;23:16-20.
12. Uppili Ragunathan S. An innovative method to reduce vat dyes electrolytically by avoiding toxic sodium hydrosulphite, California State Science Fair, Project Number S0522; 2005.
13. Rekha R, Taroporewala KS. Ecofriendly alternative to reducing agents used for vat dyeing on cellulose and polyester cellulose blends (part- III), Man Made Textiles in India. 2002;45(4):127-132.
14. Nair GP. Sodium bisulphite to reduce hydrosulphite requirements in package vat dyeing. Colourage. 2005;52(5):69-72.
15. Aspland JR.. Vat dyes and their application. Textile Chemist and Colourists. 1992;24:22-24.

16. Haworth D, Kilby W. Developments in the dyeing of piece goods with vat dyes. Journal of the Society of Dyers and Colourists. 1998;67(12):508-513.
17. Deo HT, Roshan Paul. Standing bath technique for indigo denim dyeing. International Textile Bulletin. 2004;50(2): 66-67.
18. Baumgarte U. Developments in vat dyes and in their application 1974-1986, Colourage Annual. 1989;90: 33-37.
19. AATCC Test Method 61-1996: Colour fastness to laundering: Home and commercial-accelerated, Technical Manual of the AATCC, Research Triangle Park, USA; 2003.
20. AATCC Test Method 61-1998: Colour fastness to light, Technical Manual of the AATCC, Research Triangle Park, USA; 2003.
21. AATCC Test Method 135-1985: Colour measurement of textiles: Instrumental, Technical Manual of the AATCC, Research Triangle Park, USA; 2003.
22. Saville BP. Physical testing of textiles. Wood Head Publishing Limited and CRC Press, Cambridge, England; 2004.
23. Karthiyekan, Joshua Alexander. Waste minimization in textile industry. The Indian Textile Journal. 2008:35-45.
24. Karen Leonas K, Michael Leonas L. Textile process waste water permits: An update and strategies'. American Dyestuff Reporter. 1994:26-34.
25. Manivasagam N. Industrial effluents – origin, characteristics, effects, analysis and treatment. Sakthi Publications, Coimbatore, India; 1997.
26. Teli MD, Roshan Paul, Pardeshi PD. Recovery and reuse of dyes, chemicals. The Indian Textile Journal. 2000:11-19.

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