Design and Development of Environment Friendly Textile Dyeing Machine

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Abstract-This work describes the novel development, installation, and operation of a textile dyeing machine that used one of the most emerging technologies based on Advanced Oxidation Processes (AOPs). The new machine was found to be capable of reducing water consumption by 57% and process time by 40%, without compromising textile dyeing quality. Different shades were dyed on newly built dyeing machine using three different types of reactive dyes, Vinylsulphone, Monofluorotriazine, and Monochlorotriazine. The washing and rinsing of dyed fabrics were carried out at the completion of dyeing, both in conventional and newly developed dyeing machines. Fabrics washed in both machines was compared in terms of color fastness, color alteration, color fading, and final appearance. Overall results from the environment point of view have indicated that the new dyeing machine is a promising alternative to the conventional machine because its wastewater exhibited lower pH, conductivity, and colour strength.

Keywords-Jet Dyeing Machine, AOPs, Ozone, Reactive Dyes, Washing

I. INTRODUCTION

In recent years, environment seems to be the driving force for the development of new technologies which should not only consume less energy and water, but should also reduce wastewater quantity and toxicity. Textile industry is no exception and number of efforts have been made in the past for the reduction of pollution load in terms of several parameters such as chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solids (TSS), colour strength, pH, and temperature [i, ii].

Application of ozone (O_3) in various industrial applications has been widely investigated [iii]. The high oxidation potential of ozone (2.07 V) is found to be capable to degrade aromatic structures and unsaturated bonds, such as -C=C- or -N=N-, which are commonly found in chemical structures of textile dyes[iv]. The oxidation power of ozone is the result of extra oxygen atom that can easily breakdown these chemical structures into simpler biodegradable products [v]. Moreover, reactions of ozone with other chemicals, such as textile dyes, do not produce any sludge [vi] or toxic by-products [vii]. Ozone also lowers COD of the effluent making it suitable to discharge into water streams [viii]. Another merit of using ozone in industrial applications is that ozone is always applied in its gaseous state, and thus it does not increase the volume of sludge and wastewater.

Ozone can react with organic materials using two different pathways, firstly by direct oxidation as molecular O_3, and secondly by indirect reaction through hydroxyl (OH) radicals [ix, x]. In water, ozonation process may undergo following reactions:

$$O_3 + OH^- \rightarrow HOO\bullet + O_2 \quad \text{(i)}$$

$$O_3 + O^{-2} \rightarrow O\bullet_3 + O_2 \quad \text{(ii)}$$

$$O\bullet_3 + H^+ \rightarrow HO\bullet_3 \quad \text{(iii)}$$

$$HO\bullet_3 \rightarrow HO\bullet + O_2 \quad \text{(iv)}$$

The reaction between OH ions and O_3 can lead to the generation of super oxides anion radicals O_2 and hydroperoxyl radicals HOO• [xi]. When the pH of aqueous solution is acidic, O_3 is available in molecular form [xii].

This pilot-scale study investigated the efficiency of a newly developed textile dyeing machine equipped with ozone application. The application of ozone gas in the machine effectively decolorized the used washing and rinsing wastewater. This wastewater can then be subsequently reused in the same process.

II. MATERIALS AND METHODS

2.1 MATERIALS

2.1.1 Textile material, dyes and chemicals

A textile knitted fabric (100% cotton) having 200 gsm and made out with 21/s ring-spun yarn was used throughout the study. Selected commercial reactive dyes (Dystar, Pakistan) used in the study are summarized in Table I.

TABLE I
REACTIVE DYES AND RECIPES USED IN THE EXPERIMENTAL WORK

Dye Commercial Name	Colour strength (% owf)	C.I. Name	Type of Reactive dye
Shade: RED			
Remazol Red RR	5	Mixed dye	Vinylsulfone
Remazol Brillian Blue BB	0.5	C.I. Reactive Blue 220	
Remazol Golden Yellow RNL	0.5	C.I. Reactive Orange 107	
Shade: Yellow			
Cibacron Yellow F-3R	5	C. I. Reactive	Monofluorotriazine
		Orange 91	
Cibacron Red F-B	0.5	C. I. Reactive Red 184	
Cibacron Blue F-R	0.5	C. I. Reactive Blue 182	
Shade: Blue			
Procion Yellow H-EXL	0.5	C. I. Reactive Yellow 138	Monochlorotriazine
Procion Brilliant Red H-EGXL	0.5	C. I. Reactive Red 231	
Procion Blue H-EXL	5	C. I. Reactive Blue 198	

Chemical auxiliaries like sodium sulphate (Na_2SO_4) and sodium carbonate (Na_2CO_3) used were of commercial grade and used without any further purification.

2.1.2 Development of dyeing machine

Newly developed dyeing machine Fig. 1 was consisted of a regular 10 kg jet machine (Thies GmbH & Co. KG, Germany), equipped with an O_3 generator (Kaufman, OZ-50, Germany), O_3 analyzer (Ozonova, UVP 200, Germany), injector pump, O_3 catalyst (destroyer), O_3 gas leak detector, ORP meter, and ambient air O_3 monitor (Gfg, Micro III, Germany).

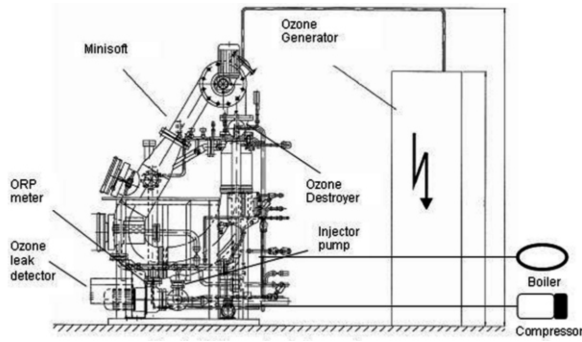

Fig. 1. Schematic diagram of newly developed textile dyeing machine

Fig. 2. Picture of newly developed textile dyeing machine

The O_3 gas was generated using the ozone generator designed to produce up to 50g /hr of O_3. The flow rate O_3 gas was kept at the rate of 500 L/min. To avoid heating up of ozone generator, cooling water was circulated in the generator. The transfer of O_3 gas from the ozone generator to the dyeing machine was carried out with the help of an injector pump connected to machine through a stainless pipe (2-inch internal diameter). The O_3 was injected at the bottom of dyeing machine, next to the suction of main water pump to get homogenous mixing of O_3 with the used washing and rinsing wastewater. Injection of O_3 at this location of the machine can ensure maximum mass transfer of O_3 gas into the wastewater. Unused and non-reacted O_3 gas from the machine was destroyed using a catalyst destructor. In order to monitor the dissolved O_3 in the machine, a self-cleaning ORP (Oxidation-Reduction Potential) meter (RAB automation, Model 39300, Germany) was also installed. The ORP meter measured the dissolved O_3 with the help of electrodes. An ozone leak detector (SK 110, Germany) was also installed on the machine to detect the O_3 gas around the machine.

2.3 METHODS

2.3.1 Color removal efficiency

Dyed fabrics in newly developed dyeing machine were subjected to O_3 application. This treatment was continued until the wastewater is decolorized around 95%. The color removal (%) was determined using the following equation:

$$D = \frac{C_0 - C_t}{C_0} \times 100$$

D = decolorization (%), C_0 = initial concentration of dye,
C_t = concentration of dye at time t

2.3.1 Evaluation of color differences and fastness properties

The color fastnesses of dyed fabrics were assessed using AATCC test methods. AATCC 61-2001-2A and AATCC Test Method 8-2001 were used to evaluate color change and rubbing fastness, respectively [xiii, xiv]. The CIELAB color values of dyed fabrics were measured using spectrophotometer (Spectraflash SF 600 PLUS CT, Datacolor, USA).

III. RESULTS AND DISCUSSIONS

3.1 Machine efficiency

After loading 5kg of fabric in the dyeing machine, it was filled with 50 liters of fresh water at liquor ratio (L:R) of 1: 10 and ozone application was initiated. Characteristics of treated wastewater and experimental conditions for various shades are summarized in Table II.

TABLE II
CONDITIONS AND EFFICIENCIES OF THE MACHINE

Shade	Ozone Dose (mg/m) ppm	Ozone Exposure Time (min)	Conductivity (µS/cm)	pH	Temp. (⁰C)	Color removal (%)
RED	167	0	9	9.98	42	-
		10	17	9.65	41	67
		20	25	9.1	39	84
		30	27	8.5	37	91
		40	31	8.25	34	94
		50	38	7.8	32	96
Yellow	133	0	11	10.1	48	-
		10	21	9.51	44	75
		20	27	9.18	37	87
		30	31	8.2	35	99
Blue	167	0	6	9.81	41	-
		10	10	9.12	39	77
		20	13	8.68	37	84
		30	21	8.21	34	89
		40	28	7.7	32	93
		50	29	7.48	30	97

For Red shade, the O_3 dose and air flow were set to 10g/hr and 600 LPM, respectively. This particular flow rate maintained the differential pressure (ΔP) of the machine on negative side to avoid build-up of O_3 in the machine. At this particular flow rate, O_3 concentration in the feed gas was found to be 0.22 mg/l. There was no adjustment in the pH of the wastewater before or during the ozonation. However, pH was observed to be changing during ozonation. After 50 minute of O_3 treatment, the colour of wastewater was significantly reduced to almost colourless solution yielding 96% colour removal. In case of Yellow shade, 99% colour removal was achieved after 30 minutes of treatment using 133 mg/m of O_3 dose. Similar trend was observed in Blue shade.

The pH values of wastewaters were also measured and displayed in Fig. 3.

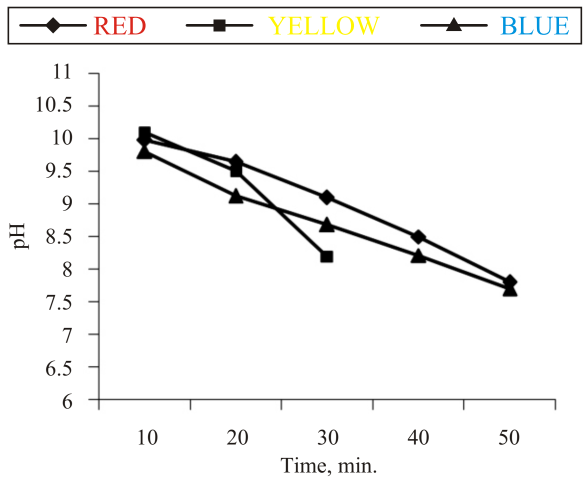

Fig. 3. Effect of treatment time on

At the start of O_3 application, the starting pH of the wastewater was around 10, which gradually dropped to around 7.5 in 30-50 minutes. This drop in pH during O_3 application was in line with similar studies [xv, xvi, xvii].

3.2 Colour difference values

The colour difference values between reference fabric and those washed in new are summarized in Table III.

TABLE III
COLOR DIFFERENCES OF REFERENCE AND NEW MACHINE WASHED FABRICS

Shade	ΔL*	Δa*	Δb*	ΔC*	Δh*	ΔE^*_{cmc}
Red	-0.86	-0.19	0.11	-0.03	0.22	0.89
Yellow	0.03	0.00	0.10	-0.09	0.01	0.10
Blue	-0.56	0.41	0.20	0.41	-0.20	0.72

The results pertinent to RED shade clearly indicate that minor differences in lightness (ΔC^*= -0.03), Hue (ΔH^* = 0.22), and total difference (ΔE^*cmc=0.89) were noticed. Similarly, negligible colour differences were observed in Yellow and Blue shades.

3.3 Fastness properties

The fastness results are summarized in Table IV. The results clearly show that fabrics processed on conventional and newly developed machines exhibited identical fastness properties, and most ratings were found to be in the range of 4.5 to 5, which indicates commercially acceptable results.

TABLE IV
COLOR FASTNESS AND CHANGE OF SHADE PROPERTIES OF REFERENCE AND NEW MACHINE WASHED FABRICS

Shade	Dyes fabrics	Rubbing		Colour Staining			Change of Shade
		Dry	Wet	Cotton	Nylon	PES	
Red	Reference	5	4.5	4.5	5	5	-
	New Machine Washed	4	5	4.5	5	5	4.5
Yellow	Reference	5	5	5	5	5	-
	New Machine Washed	5	5	5	5	5	4.5
Blue	Reference	5	4.5	4.5	5	5	-
	New Machine Washed	5	5	4.55	5	5	5

The change of shade data for all three shades confirms the fact that new machine provided similar dyeing results.

IV. CONCLUSION

It is observed that new machine would require far less O_3, compared to conventional O_3 applications that were tried as an end-of-pipe treatments to remove colour in final, complex, and highly coloured wastewater. A comparative analysis pertaining to water consumption in new machine also showed that 57% less water was used in new machine. This saving of water due to the fact that rinsing process in new machine was completed with 3 fills and drains as opposed to 7 in conventional machine. Consequently, if the new machine is used in the industry at liquor ratio of 1:8, it is possible to use only 24 L water for one kilogram of fabric, instead of using 56 L water in conventional machine. The new machine also did not use any steam, and thus proved to be a low energy intensive compared to the conventional machine.

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REFERENCES

[i] H. Selcuk. (2005, Mar.). Decolorization and detoxification of textile wastewater by ozonation and coagulation processes. *Dyes Pigments*. [Online]. *64(3),* pp. 217-222. Available:http://www.sciencedirect.com/science/article/pii/S0143720804001147

[ii] I. Arslan-Alaton. (2007, Jan.). Degradation of a commercial textile biocide with advanced oxidation processes and ozone. *J. Environ Manage*. [Online]. *82*(2), pp.145-154. Available:http://www.sciencedirect.com/science/article/pii/S0301479706000193

[iii] H. Zhou and D. W. Smith. (2002, Jul.). Advanced technologies in water and wastewater treatment. *J. ENVIRONENG SCi*. [online]. *1(4),* pp. 27-264. Available:http://www.nrcresearchpress.com/doi/abs/10.1139/s02-020#.U6CVDfmSzX9

[iv] A. C. Silva, J. S. Pic, G. L. Sant'Anna Jr & M. Dezotti. (2009, Sep.). Ozonation of azo dyes (Orange II and Acid Red 27) in saline media. *J. of Hazard. Mater.*[Online].*169(13),* pp.965-971. Available:http://www.sciencedirect.com/science/article/pii/S030438940900613X

[v] C. C. Alton. (1983). Recycling dye wastewater through ozone treatment. *Text. Ind. 7,* pp. 26-30.

[vi] N. H. Ince and D. T. Gonenc. (1997). Treatability of a textile azo dye by UV/H_2O_2. *Environ. Technol.* [Online]. *18(2)*, pp. 179-185. Available:http://www.tandfonline.com/doi/pdf/10.1080/09593330.1997.9618484

[vii] F. Gahr, F. Hermanutz and W. Opperman. (1994). Ozonation an important technique to comply with new German law for textile wastewater treatment. *Water Sci. Technol.30* pp. 255-263.

[viii] Y. Xu, R. E. Lebrun, P. J. Gallo & P. Blond. (1999). Treatment of textile dye plant effluent by nanofiltration membrane. *Sep. Sci. Tech.* [Online]. *34(13),* pp. 2501-2519. Available:http://www.tandfonline.com/doi/pdf/10.1081/SS-100100787

[ix] I. Arslan, I. Akmehmet Balcioglu & T. Tuhkanen. (1999, Dec.). Oxidative treatment of simulated dyehouse effluent by uv and near-UV light assisted Fenton's reagent. *Chemosphere,* [Online]. *39(15),* pp. 2767-2783. Available:http://www.sciencedirect.com/science/article/pii/S0045653599002118

[x] S. Baig & P. Liechti. (2001). Ozone treatment for biorefractory COD removal. *Water Sci. Technol.* [Online]. *43*(2), pp.197-204. Available:http://www.iwaponline.com/wst/04302/wst043020197.htm

[xi] C. Gottschalk, J. A. Libra & A. Saupe. (2009). *Ozonation of water and waste water: A practical guide to understanding ozone and its applications*. (2nd ed.) [Online]. Available:http://books.google.com.pk/books?hl=en&lr=&id=MGpBHLw2POsC&oi=fnd&pg=PR5&dq=Ozonation+of+Water+and+Waste+Water.&ots=INij_yLMc3&sig=HZC7ei1Rm3CaFKjQWF60YYy62f0#v=onepage&q=Ozonation%20of%20Water%20and%20Waste%20Water.&f=false

[xii] W. Chu & C. W. Ma (2000, Aug.). Quantitative prediction of direct and indirect dye ozonation kinetics. *Water Res.* [Online]. *34(12),* pp. 3153-3160. Available:http://www.sciencedirect.com/science/article/pii/S0043135400000439

[xiii] *Colorfastness to Laundering*, AATCC Testing Method 61-2001-2A, 2001.

[xiv] *Colorfastness to Crocking*, AATCC Testing Method 8-2001,2001.

[xv] U. K. Khare, P. Bose & P. S. Vankar. (2007, Nov.). Impact of ozonation on subsequent treatment of azo dye solutions. *J. Chem. Tech. Biot.* [Online]. *82(11),* pp.1012-1022. Available:http://onlinelibrary.wiley.com/doi/10.1002/jctb.1785/full

[xvi] E. Oguz & B. Keskinler. (2008, Mar.). Removal of colour and COD from synthetic textile wastewaters using O_3, PAC, H_2O_2 and HCO_3^-. *Journal of Hazardous Materials,* [Online]. *151(23),* pp. 753-760. Available:http://www.sciencedirect.com/science/article/pii/S0304389407009090

[xvii] O. Avinc, H. A. Eren & P. Uysal. (2012, Dec.). Ozone applications for after-clearing of disperse-dyed poly (lactic acid) fibres. *Color. Technol.* [Online]. *128(6),* pp. 479-487. Available:http://onlinelibrary.wiley.com/doi/10.1111/j.1478-4408.2012.00403.x/full