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CHARACTERIZING AND MEASURING TEXTILE EFFLUENT POLLUTION USING A MATERIAL BALANCE APPROACH: BANGLADESH CASE STUDY

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ABSTRACT

Textile dyeing industries dye fabric in different shades and the entire process is made up of a variety of stages that can be broadly categorized as pre-dyeing, dyeing and post-dyeing. Measuring textile dyeing effluent characteristics is a complicated procedure as the effluent pollution load changes with the dye shade and dyeing procedure practiced in the industry. For the effective treatment of effluent, to maximize the efficiency of the dyeing process and to monitor pollution it is important to measure the effluent load properly.

In this study we have developed a methodology to characterize and determine pollution load using a material balance approach. Effluent samples were collected for each stage of the knit fabric dyeing process from the dye machine outlet of a semi-automated dyeing plant. A pollution load database was developed for the stages involved in different dye shades. Using the database and material balances, the effluent volume and the pollution load can be calculated for any dye shade, dye cycle, production time and production capacity of the dyeing plant.

Keywords: Textile Effluent, Winch Dyeing, Dye Shade, Pollution Load, Material Balance

1. INTRODUCTION

The ready-made garment (RMG) sector has become one of the largest manufacturing sectors in Bangladesh with over 4500 registered apparel manufacturing units. RMG sector accounts 80 per cent of Bangladesh’s total export, which was approximately USD $15.6 Billion in 2010 [1]. The growth in this sector, and other small and medium scale enterprises, undoubtedly has a positive effect on national economic development but there are also negative implications. Textile effluent is often a major source of environmental pollution, especially water pollution. Among the various stages of textile manufacturing most pollution is generated in the fabric colouring stage (dyeing and bleaching). The textile dyeing wastes contain unused or partially used organic compounds, strong colour, high chemical oxygen demand (COD) and biochemical oxygen demand (BOD) [2-4]. Under the Bangladesh Environment Conservation Act (ECA 1995) and Environmental Conservation Rules (ECR 1997) textile dyeing industries are categorized as “Red industries”, and must treat and monitor the wastewater quality conforming to national discharge quality standards [5-7]. However, in many cases, this wastewater is disposed untreated to the nearby rivers or wetlands [8, 9].

Water quality analysis is an expensive and, for some parameters, a complicated procedure requiring expert knowledge and special equipments. It is made even more complex because textile industry wastewater is rarely uniform through time [2, 8]. For example, textile dyeing involves several process baths that will be dropped at intervals and each will contain a range of pollutants at various concentrations depending on the individual process. Textile industries dye fabric in different dye shades, which are broadly classified as dark, medium and light, as well as bleaching fabric to become white. Dyeing sequence and effluent pollution load change with the dye shade that the manufacturer tries to achieve. Textile industries dye one or multiple shades at any given time according to the demand of the buyers; therefore, the effluent pollution load varies accordingly.

To treat and monitor the quality of wastewater, and to minimize chemical use it is important to characterize the effluent and determine pollution level accurately [10]. Pollution load calculation is also important for the design and operation of effluent treatment plants (ETPs). Industry management can collect effluent samples from the factory outlet/drainage or equalization tank of an existing ETP (if any). However, the collected sample can misrepresent the actual pollution load due to the dye shade(s) being applied on the fabric at that time period, insufficient equalization tank capacity and possible contamination of factory outlet/drainage from various in-house sources (e.g. construction work, washing equipment etc.) [9].

We have developed a methodology to characterize and determine pollution load using a material balance. In this method, effluent samples were collected from the outlet of the dyeing machine from each stage of knit fabric dyeing process at a semi-automated dyeing plant. Samples were analyzed in the laboratory. A pollution load database was developed for the stages involved in different dye shades. Using the database and material balances, the effluent volume and the pollution load can be calculated for any dye shade, dye cycle, production time and production capacity of the dyeing plant. This approach involves gaining a detailed understanding of the production process. This method can be useful to guide the design of new ETPs and to optimize existing ETP performance. It can also facilitate manufacturing process optimization, highlight errors in machine operation and enable environment agencies to more efficiently monitor pollution from textile industries.

2. PROJECT APPROACH

In order to address the issues of increasing water pollution from textile industries and inadequate treatment, the project "Managing Pollution from Small- and Medium-Scale Industries in Bangladesh" was initiated. It was funded by the EU Asia Pro Eco Programme and the DFID Knowledge and Research Programme, between 2003 and 2006. The aim of the project was to reduce pollution while maintaining the profitability of the industries and thereby ensure the incomes of the employees as well as the livelihoods of those who depended on the natural resources that were being impacted. The activities therefore involved cleaner production and improved wastewater treatment. The project was implemented by the Stockholm Environment Institute (SEI), the Bangladesh Centre for Advanced Studies (BCAS) and the University of Leeds, UK.

In this component of the project, the team worked with a composite textile industry producing knit fabric to collect effluent samples from each stage of dyeing process. The purpose of the work was three-fold:

1. To develop a pollution load database for the stages involved in different dye shades.
2. To develop a simple but effective material balance approach to calculate effluent volume and pollution load (daily and yearly) of the dyeing plant using the pollution load database.
3. To help industries to install compatible effluent treatment plants (ETP) and to operate existing ETPs efficiently.

3. DYEING STAGES

The factory in which the research was conducted undertakes knitting, dyeing and sewing of cotton (usually referred to as a composite textile industry). The dyeing unit of a composite textile industry contributes the major part of the total effluent produced from the manufacturing process. The industry used semi-automated winch dyeing machines with a daily dyeing capacity of 10 tonnes which was split between dark colours (35 per cent), medium shades (15 per cent), light shades (30 per cent) and bleached whites (20 per cent). Winch dyeing involves various stages or unit processes, which include pre-treatment of the fabric, dyeing of the fabric and post-treatment of dyed fabric. Major steps involved in winch dyeing process are [2, 8, 11]:

3.1 Pre-treatment

Scouring: To remove impurities in the cotton. This is done at temperatures of approximately 100^{o}C with alkali, detergent, and sequesterent.

Bleaching: To whiten fabric using sodium hypochlorite or hydrogen peroxide. Most factories use hydrogen peroxide as sodium hypochlorite is highly toxic; however it is also cheaper than hydrogen peroxide.

Neutralization: Scouring and bleaching stages are highly alkaline. In the neutralization stage an acid (usually acetic acid) is used to bring down the pH value to a compatible rage for dyeing. This is necessary to ensure that the dye does not react with the fabric too soon in the process.

3.2 Dyeing

Dyeing: Fibre reactive dyes, of both the vinyl sulphone and mono chloro triazine type are predominantly used in Bangladesh for knitted cotton fabrics. They require large quantities of salt and alkaline conditions for fixation onto the fabric, and as the salt is not used up in the process, effluents contain high concentrations of salt. Some polyester and polyester blends are also dyed using disperse dyes, although quantities are much lower that for direct dyes. The effluents contain unfixed dyes (10-30 per cent of quantity added to the dyebath), organic acids, carriers, reducing agents, levelling agents, defoamers, levelling agents and dispersants.

3.3 Post-Treatment

Rinsing: Rinsing is used to washout excess chemicals (e.g. unfixed dye) from the fabric. The rinse process is a concurrent water flowing system where fresh water is added to the dye-bath and the liquor from previous stage is discharged keeping the machine outlet open until fresh water starts draining. The volume of rinsing water used can be calculated from the inlet flow rate and time.

Softening and Finishing: After several rinses and washes, softeners and other chemicals are generally applied to knitted cotton fabrics. This stage provides the fabric with its aesthetic, chemical and mechanical properties, such as flame retardant, mildew resistant and wrinkle resistant.

The number of stages may vary according to the buyers' specifications which influence dye shade, dye quality and other chemicals used. Each stage requires certain processing times to treat the fabric and after treatment the process liquor used to treat the fabric is discharged as wastewater. Depending on the amount of fabric being died and the liquor ratio used, each stage in the process discharges between a few hundred to thousand litres of wastewater. Since a composite textile factory usually operates 24 hours a day and may have a number of machines operating at any one time (usually somewhere between two and twelve depending on the factory size), this can amount to a considerable pollution burden on the local environment.

4. SAMPLE COLLECTION

Wastewater samples were collected from winch machine outlets after every stage of the dyeing process. Three sets of samples of process liquor were collected each time the dye bath was emptied (at the beginning, the middle and the end of discharging process) and then mixed uniformly to get a representative sample. The samples were preserved below 4°C and transported to the analytical laboratory as quickly as possible to minimize the effect of spontaneous chemical reactions and microbial activity in the samples. Samples testing was undertaken at the Bangladesh University of Engineering and Technology (BUET) and started within 24hrs of collection.

5. MATERIAL BALANCE TECHNIQUE

For each stage of dyeing, the following parameters were assessed: pH, total dissolved solid (TDS), total suspended solid (TSS), 5-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD) and sulphate (SO_4^{2-}). All parameters are measured in mg per litre (mg/L) except pH. The effluent quantity discharged from each stage was measured in litres. Total volume of wastewater generated for any single dye shade can be found from the cumulative wastewater generated at each stage in the dyeing process. Any pollution indicating parameter for effluent generated from a single dye shade can be calculated from the weighted average. To calculate the weighted average of any specific parameter, such as TDS, the effluent volume (litre) discharged in a single stage was multiplied by the TDS concentration (mg/L) of the corresponding stage effluent water; the result will give total TDS (mg) present in the corresponding stage effluent water. The summation of total TDS (mg) for every stage involved will give the cumulative TDS value (mg) for that specific dye shade dyeing. Dividing the cumulative TDS (mg) by cumulative effluent water generated (litre) will give the weighted average of TDS concentration (mg/L) present in effluent generated by the specific dye shade dyeing.

In mathematical format,

weighted average of total dissolved solid (TDS) concentration (mg/L) of effluent generated in a specific dye shade dyeing

$$= \frac{\Sigma(\text{[TDS concentration in single stage effluent]} \times \text{[corresponding effluent volume]})}{\Sigma(\text{effluent volume generated in single stage})}$$

$$= \frac{\Sigma([\text{mg/L}] \times [\text{L}])}{\Sigma(\text{L})} = \frac{\text{mg}}{\text{L}}$$

Calculating the average of pH is a little different. At first, the pH values were converted into $[H^+]$ and $[OH^-]$ ions; the cumulative $[H^+]$ and $[OH^-]$ ions were balanced and then the balanced ions were re-converted into pH value.

6. RESULTS

Effluent water samples for the dark shade dyeing process were collected from a 400 kg knit fabric dyeing batch. Different stages of dark shade dyeing and their pollution loads are given in Table 1. Pre-treatment of fabric included scouring, hot wash with detergent, cold wash and neutralization with acid (acetic acid). In the dyeing stage, electrolyte (globar salt), alkali and other chemicals were added along with different dyes. Post-treatment of dyed fabric required lots of water for rinsing, a cold wash, a hot wash with soaping agent, neutralization with acid, washing with fixing agent and washing with softener. Different volumes of wastewater were generated from these different stages (Table 1).

Different stages of the medium shade dyeing are shown in Table 2. For medium shade dyeing, effluent water samples were collected from a 189 kg knit fabric dyeing batch. Pre-treatment stages for the fabric were scouring, hot wash with detergent, neutralization with acid wash and wash with enzyme solution. Like, dark shade dyeing, electrolyte, alkali, other chemicals and different colour dyes were used in the medium shade dyeing stage. Post-treatment of dyed fabric required lots of rinsing, an acid wash, a hot wash with soaping agent and a wash with softener (Table 2).

Wastewater samples for the light shade dyeing process were collected from a 600 kg knit fabric dyeing batch. Pollution indicating parameters and volume of wastewater generated in light shade dyeing process are shown in Table 3. The processing stages were similar to those for medium shade dyeing, except the enzyme wash.

Bleached white fabric processing stages were: scouring, wash with soaping agents, neutralization with acid and wash with softeners (Table 4). For that kind of fabric no dyeing stage was involved. Wastewater samples for bleached white fabric processing were taken from a 286 Kg knit fabric batch.

Table 1: Characteristics of dark shade dyeing stages of a Semi-Automated Winch Dyeing Machine

Amount of fabric: 400 Kg

Stages	Volume of water (litre)	pH	TDS (mg/L)	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	SO_4^{2-} (mg/L)
Scouring	2600	12	5850	396	2050	10120	180
Hot wash	2600	11.4	3060	10	625	3050	100
Cold Wash	2600	10.3	693	8	490	2420	25
Neutralization	2600	5	536	4	290	1441	10
Dyeing	2800	11	57800	16	725	3520	33000
Rinsing	10400	10.1	6700	11	275	718	10000
Cold Wash	2600	8.9	550	20	45	89	700
Hot Wash with Soaping Agent	2600	9.4	950	30	235	1164	1000
Rinsing	5200	8.8	445	23	215	428	1000
Rinsing	5200	7.6	196	15	32	63	100
Neutralization	2600	4.45	303	5	360	899	200
Rinsing	10400	5.3	204	10	175	344	50
Wash with Fixing Agent	2600	5.5	222	4	120	240	5
Softening	2600	4.6	244	477	76	162	30
Bangladesh Standard for effluent		6.5-9	2100	100	150	400	400

Table 2: Characteristics of medium shade dyeing stages of a Semi-Automated Winch Dyeing Machine

Amount of fabric: 189 Kg

Stages	Volume of water (litre)	pH	TDS (mg/L)	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	SO_4^{2-} (mg/L)
Scouring	2100	10.54	9906	110	2250	8660	525
Hot wash	2100	10.33	5407	174	1700	5780	275
Neutralization (Acid wash)	2100	5.97	2977	103	750	2480	25
Wash with Enzyme solution	2100	5.08	294	10	420	929	75
Dyeing	2000	9.48	61280	455	450	1118	25000
Rinsing-1	4200	9.25	22115	362	180	366	10750
Rinsing-2	4200	8.66	2057	83	88	146	1125
Acid wash	2100	5.43	920	125	340	754	275
Rinsing	4200	6.21	482	15	180	358	175
Hot wash with soaping agent	2100	7.16	330	12	150	300	25
Hot wash Rinsing	4200	7.19	292	40	50	102	50
Softening	2100	5.32	340	32	650	1596	25
Bangladesh Standard for effluent		6.5-9	2100	100	150	400	400

Table 3: Characteristics of light shade dyeing stages of a Semi-Automated Winch Dyeing Machine

Amount of fabric: 600 Kg

Stages	Volume of water (litre)	pH	TDS (mg/L)	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	SO_4^{2-} (mg/L)
Scouring	4400	10.54	9906	110	2250	8660	525
Hot wash	4400	10.33	5407	174	1700	5780	275
Neutralization (Acid wash)	4400	5.97	2977	103	750	2480	25
Dyeing	4200	9.49	55258	313	700	2300	47500
Rinsing	17600	9.37	16396	295	390	1060	11000
Acid wash (50^0C)	4400	7.93	4227	53	350	920	2500
Rinsing	17600	7.43	1167	4	210	460	625
Hot wash	4400	7.89	1123	9	440	1000	500
Rinsing	17600	7.74	471	41	390	600	25
Softening	4400	5.84	439	606	290	1840	1
Bangladesh Standard for effluent		6.5-9	2100	100	150	400	400

Table 4: Characteristics of bleached white fabric processing stages of a Semi-Automated Winch Dyeing Machine

Amount of fabric: 286 Kg

Stages	Volume of water (litre)	pH	TDS (mg/L)	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	SO_4^{2-} (mg/L)
Scouring	2100	8.06	12728	620	2700	9400	1
Soaping	2100	8.17	5864	8	1600	3570	1
Neutralization	2100	5.52	3016	10	1000	2256	5
Softener Wash	2100	5.78	1778	27	900	1660	1
Bangladesh Standard for effluent		6.5-9	2100	100	150	400	400

Effluent water pollution load and volume for different dyeing shades calculated using the material balance approach are shown in Table 5. Bleached white fabric processing generated less effluent water (29 L/kg fabric), whereas, medium shade dyeing stages generated the most (177 L/kg fabric), which is higher than Bangladesh (BD) standard of 100 L/kg fabric. Effluent water generated by the dark and light shade dyeing stages was also much higher than BD standard.

Table 5: Characteristics of different Shade Dyeing by a Semi-Automated Winch Dyeing Machine

Type of Shade	Amount of Fabric (Kg)	Volume of water used (litre)	Volume of water used per unit of fabric (litre/Kg)	pH	mg/L				
					TDS	TSS	BOD_5	COD	SO_4^{2-}
Composite of Dark Shade	400	57400	**144**	**10.81**	4690	51	334	1296	3632
Composite of Medium Shade	189	33500	**177**	**9.59**	8051	125	482	1474	3086
Composite of Light Shade	600	83400	**139**	**9.56**	7859	143	549	1654	5052
Composite of White	286	8400	**29**	**6.29**	5847	166	1550	4222	2
Bangladesh Standard			**100**	**6.5-9**	2100	100	150	400	400

Note: All parameters exceeding the BD standards are shaded.

7. DISCUSSION

As can be seen in Table 5, in almost all processes the effluent parameters exceeded the Bangladesh standards. The composite concentrations for TSS were not substantially higher than the Bangladesh standard, with the highest only 66 per cent greater, but the other four were significantly higher: volume of water used (39 – 77 per cent) TDS (123-283 per cent), BOD_5 (123-933 per cent), COD (224-956 per cent) and SO_4^{2-} (671-1163 per cent). These figures suggest that the textile manufacturers could take steps to reduce the effluent volume and pollution loads. More specifically, reviewing the processes that produce the highest concentrations of pollutants can enable manufacturers to pinpoint particular areas for improvement and highlight inefficiencies that could be costing them money. For example, in for dark and medium shades, the baths that have highest pollution loads are scouring, hot wash and dyeing, and for light shades scouring and dyeing (Tables 1-3).

Bleached fabric processed effluent contained 3 to 4 times higher BOD_5 and COD than all the dyeing processes. This is due to bleached fabric processing consuming less water, therefore, the corresponding effluent contained relatively concentrated bleaching agents (in the scouring bath) and acetic acid (in the acid wash), which can be the reasons for high TSS, BOD_5 and COD concentration. The two most polluting processes for bleached fabrics appear to be scouring and soaping. Due to the high concentration of bleaching agents and acetic acid, the bleached white fabric processed effluent was found acidic. Effluent generated from the dyeing processes was rather alkaline due to the alkaline chemicals used in scouring, hot wash and dyeing. In bleached white fabric processing, there were no dyeing stages involved; therefore, no electrolyte (globar salt) was used in the process, which caused low SO_4^{2-} presence in corresponding effluent water.

From our research experience, we have observed that in many cases effluent treatment plant (ETP) operators assumed effluent generated from dark shade dyeing was the most polluted and that generated from bleached white fabric processing was the least. This conclusion is formed principally due to the colour of the dye effluent. But from our pollution load calculation it was found that effluent from the production of bleached whites can be more polluted than that from colouring processes, and that even within the dyeing process the non-coloured bath water e.g. scouring and hot wash, can be more polluted than the dye baths themselves.

8. CONCLUSION

A material balance approach has been developed to characterize and determine effluent volume and pollution load. Effluent samples were collected from a knit fabric dyeing industry. A pollution load database was developed for the stages involved in different shade dyeing. Using the database and material balance approach, the effluent volume and the pollution load were calculated for different shade dyeing. The material balance approach offers manufacturers, ETP operators and environment agency officials, a more accurate way of assessing the quality of effluent from all the processes involved in the dyeing and bleaching industry. For manufacturers and industry management it offers an opportunity to monitor the efficiency of a process, as it can highlight waste e.g. higher TDS concentration can suggest where dye is not being effectively fixed to the fabric. For ETP operators it also provides information that will enable them to optimize their processes, for example by blending high and low pH effluents rather than adjusting the pH with more chemicals.

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