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WASTE AUDITING AND ITS APPLICATIONS IN IMPROVING THE DYEING INDUSTRY ENVIRONMENT

V. Jegatheesan[1], S. H. Lee*, C. Visvanathan[2], L. Shu[3], and M. Marzella[4]

School of Architectural, Civil and Environmental Engineering,
Kumoh National University of Technology, Kumi 730-701, Korea

[1]Environmental Engineering Group, Faculty of Engineering, University of Technology, Sydney, P.O. Box 123, Broadway, NSW 2007, Australia

[2]School of Environment, Resources and Development, Asian Institute of Technology, P.O. Box 4, Klongluang, Pathumthani 12120, Thailand

[3]School of Civil and Environmental Engineering, University of New South Wales, NSW 2052, Australia

[4]4a Percy Street, Gladesville, NSW 2111, Australia

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Abstract : A case study on the application of cleaner production opportunities for waste minimization in dyeing industry is discussed in this paper which was conducted by Carl Duisberg Gesellschaft (CDG) South East Asia Program Office in collaboration with several Thai institutions. A waste audit was conducted as a first step in a dyeing factory, which leads to propose water reuse and waste segregation in order to implement cleaner production for waste minimization. Further more lab-scale experiments were conducted to find optimum treatment methods for the waste streams.

Key Words : cleaner production, dyeing process, waste audit, wastewater treatment

INTRODUCTION

Along with rapid industrialization, which has resulted in the rise of pollution, there is growing concern about the quality of the living environment. Requirement of good quality of the living environment has resulted in the change in the thinking of the whole concept of pollution control. Traditional pollution abatement at the discharge point, so called "End-of-pipe Treatment", is being seriously questioned. It is a fact that the end-of-the-pipe treatment only transfers the pollution from one form to the other. For example, control of air pollution results in the water pollution, which in turn results in the soil pollution and ultimately all the pollutants end up in joining the water body[1,2]. To counter the above shortcoming and to preserve the high quality of the environment new concept so called "Cleaner Production" for waste minimization is being introduced in many countries. This refers to technology designed to prevent waste emission at the source of generation itself. The philosophy behind this technology is "to produce better while polluting less"[3]. In practice this technology and its application go by many other names such as clean technology, waste minimization, pollution prevention, waste recycling, resource utilization, residue utilization, etc.[4]. This technology minimizes or totally eliminates the emission of pollutants to the environment. While investing little on the process, it is possible to save a lot of money in the disposal of waste and operation of the process. Often the capital return period is less than 5 years[5].

The project on Industrial Pollution Control Applications (IPCA) for small and medium scale industries which was launched in Bangkok and suburbs, Thailand, more than three years ago, is a collaborative undertaking of Carl Duisberg Gesellschaft South East Asia Program Office, Chulalongkorn University, Asian Institute of Technology, Industrial Works Department and lately, Chiang Mai University. The IPCA project advocates the use of cleaner production and waste minimization opportunities to control and manage pollution in small and medium scale industries. Currently IPCA project in collaboration with Environmental Engineering Program of AIT, conducted a study on the implementation of the concept of cleaner production in a medium scale dyeing industry to visualize the possibilities of pollution reduction and waste minimization[6]. A textile-dyeing factory, situated in Samuthprakan Province, was selected for this purpose.

The major objectives of the study undertaken can be summarized as follows; (i) to conduct a waste audit of the dyeing process in order to find out the extent of pollution problems. (ii) to investigate the possibilities for stream segregation to conserve water and to minimize pollution load generation from the dyeing process. (iii) to study treatment efficiency of the unavoidable wastewater streams. (iv) to set up a demonstration case study on the "Cleaner Production" in a medium scale dyeing industry.

WASTEWATER FLOW PATH AND TREATMENT SYSTEM

The process flow diagram for dyeing cotton yarn is given in Figure 1. Similar processes are

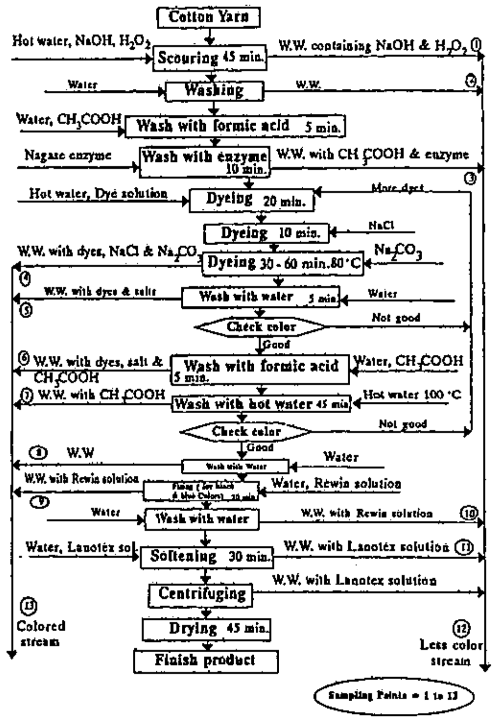

Figure 1. Process flow diagram for dyeing cotton yarn.

adopted in dyeing sweaters as well. The wastewater of the dyeing process is being discharged into two streams, one is more colored and the other is less colored. Analysis of wastewater discharged during different steps of dyeing process and from colored and less colored streams show a variety in types and strength of the wastewater generated during dyeing process. Figure 2 shows the wastewater flow path and its treatment system. Colored wastewater is supposed to be treated using ferrous sulfate and lime and then mixed with less colored and sanitary plus boiler wastewater for biological treatment. Physico-chemical treatment is given to colored wastewaster on and off. Mostly wastewater from all channels is combined in the second equalization tank and aerated in the aeration tank before being discharged into receiving body.

RESULTS AND DISCUSSION

The entire programme for data collection and

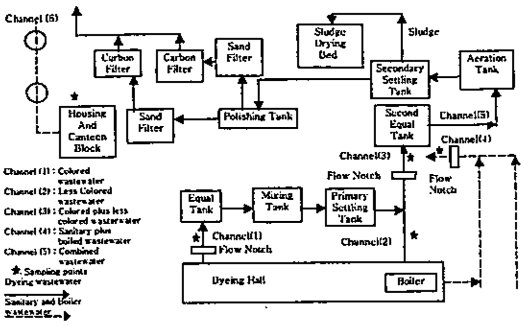

Figure 2. Schematic diagram of wastewater treatment plant.

analysis was divided into three blocks ; (i) Waste audit of the dyeing process to find out the extent of pollution problem. (ii) An evaluation of the possibilities of stream segregation during dyeing process for water reuse and its effect on the wastewater treatment. (iii) Lab-scale treatment study of the unavoidable wastewater streams.

Waste Audit

Twenty-five different colors were used in the process during a week. Maximum production of cotton yarn and sweaters were found as 4147 kg/day and 3858 kg/day respectively. Coloring frequency indicated that the factory management followed no coloring schedule, with respect to light and dark colors. Quantities of water removed during drying of dyed products measured by weighing the dyed products before and after drying were found as 0.0005 m^3/kg yarn (0.05 m^3/batch) and 0.0047 m^3/kg sweater (0.07m^3/batch). Wastewater generation was found as 0.2295 m^3/kg yarn and 0.31 m^3/kg sweater. It is compared with estimated quantities based on literature as shown in Table 1. The measured wastewater for yarn dyeing matched satisfactorily with the estimated quantity but slightly different from sweater dyeing due to less water usage for sweater washing during dyeing process. This initial water consumption audit indicated that the dyeing plant adopts a rationalized water usage program for the dyeing process.

Table 1. Comparison of wastewater generation

Type of Processes	Type of Product	Estimated* (m^3/kg)	Measured (m^3/kg)
Scouring, Bleaching, Dyeing and Washing	Cotton Yarn	0.25	0.23
	Sweater	0.41	0.31

* The volume of wastewater for dyeing process was estimated using benchmark[7].

Factory water consumption was initially reported as 2000 m^3/day. Plant survey revealed that the dyeing process consumed 80% of total water supply and remaining 20% was used in different sections including utility and domestic. 10.25% of water supply was unaccounted in this balance which stressed to implement a detailed water balance by measuring actual water supply and wastewater generation. Ground water was the source of water supply to the factory, which was measured for four continuous days by flow meters attached to ground water pumps. Maximum and average values for water supply were 1818 m^3/day and 1462 m^3/day respectively.

Detailed water balance : Daily water supply to the factory was balanced against the wastewater discharged through different flow channels. Unaccounted wastewater lied within 3.18 to 7.50%, which seemed to be due to improper maintenance of wastewater flow channels. During the audit, it was often observed that wastewater overflow was stagnant around the flow channels. This quantity of wastewater may be termed as unaccounted quantity.

In Figure 3, the total water input is 1230 m^3 while yarn and sweater productions are 3591 kg and 978.1 kg respectively. Water consumption for yarn and sweater dyeing were calculated on the basis of 0.23 m^3/kg yarn and 0.31 m^3/kg sweater. Actual wastewater flow measurements made on the respective day were considered in water output. 3.41% unaccounted wastewater was observed in this balance.

Water balance indicates that 70% of the total

Water Input = 1230 m^3/d

Input

Sweater Dyeing	= 210 m^3/d
Yarn Dyeing	= 825 m^3/d
Boiler and other utilities	= 110 m^3/d
Canteen, colony and car washing	= 45 m^3/d
Toilet, washing, drinking, cleaning	= 40 m^3/d

Output

Colored wastewater	= 648 m^3/d
Less colored wastewater	= 216 m^3/d
Sanitary plus boiler wastewater	= 184 m^3/d
Canteen, colony and car washing	= 45 m^3/d
Cooling water	= 95 m^3/d
Total	= 1188 m^3/d
Unaccounted	= 3.4 %

Figure 3. Water balance in the textile-dyeing factory.

water supplied came out from dyeing hall through colored and less colored wastewater channels and 15% came through sanitary plus boiler waste stream. Hence, 85% of total water input that proceeds towards the second equalization tank requires treatment prior to ultimate disposal.

Wastewater production : Overall production of wastewater from the factory was divided into four types; (i) Colored wastewater (Channel 1). (ii) Less colored wastewater (Channel 2). (iii) Sanitary plus boiler wastewater (Channel 4). (iv) Housing colony and canteen wastewater (Channel 6). Colored wastewater had the highest flow rates as compared to the other two channels. Flow rates of less colored and sanitary plus boiler wastewater were almost the same. Summation of flow rates from colored, less colored and sanitary plus boiler wastewater was the total wastewater flow from production activities excluding cooling water used for yarn dyeing. This cooling water neither entered into any flow channel nor being taken back for reuse. It remained stagnant around the area near to flow channels and removed by evaporation and infiltration. The measured quantity of cooling water for one batch of yarn dyeing was found to be 5 m^3.

The analysis of the effluent showed that the wastewater of the factory was alkaline. The values of total solids (TS) were quite higher than those of COD due to the usage of dissolved salts in dyeing process. ADMI values for colored and sanitary plus boiler wastewater stream were also high, which indicated improper stream segregation. According to the Standard Methods for the Examination of Water and Wastewater[8], the method developed by American Dye Manufacturers Institute (ADMI) to measure the colour of a sample is independent of hue. If two colours are judged visually to differ from colourless to the same degree, their ADMI colour values will be the same. All wastewater streams except sanitary plus boiler wastewater had BOD/COD ratio less than or equal to 0.55, which indicates the suitability of chemical treatment instead of biological treatment for those wastewaters. Daily water supply to the factory was balanced against the wastewater discharged through different flow channels. Unaccounted wastewater lied within 3.18 to 7.50% mainly due to the improper maintenance of wastewater flow channels. During auditing, it was observed that wastewater overflow got stagnant around the flow channels. This quantity of wastewater may be termed as unaccounted quantity. Water balance indicates that 70% of the total water supplied came out from dyeing hall through colored and less colored wastewater channels and 15% came through sanitary plus boiler waste stream. Hence, total 85% of water input proceeds towards the second equalization tank requires treatment prior to ultimate disposal. Inlet wastewater flow rate and COD to the equalization tank were 1345 m^3/day and 437.55 kg/day respectively. Difference in COD between inlet and outlet streams was observed to be 4.70%. This difference comes from the evaporation losses in the equalization tank.

Stream Segregation

Two wastewater flow channels are available in the wastewater flow path for separate flow of colored and colorless effluents of dyeing process. Dyeing process survey during waste audit revealed that stream segregation was practised without any experimental background of dyeing effluent characteristics. Strong color was often observed in less colored flow channel and colored wastewater was also apparent in sanitary plus boiler wastewater channel. ADMI values of grab samples at one hundred hour interval for colored, less colored and sanitary plus boiler wastewater are plotted in Figure 4. Color strengths of more than 1600 ADMI and 200 ADMI were found for less colored and sanitary plus boiler wastewater streams respectively. This experimental evidence indicated that the existing status of stream segregation was inadequate.

Wastewater samples collected on each discharge during sweater and yarn dyeing were analyzed for quality parameters. The dyeing process produced a variety of effluents with different values of color and COD. Scouring wastewater was highly alkaline and had high COD. Dyeing and first washing after dyeing were not only the major sources of wastewater color but also had high COD and TS. Wastewater analysis highlighted the drawbacks of current stream segregation strategy. Scouring wastewater with high COD was discharged along with enzyme wastewater of low COD and highly colored dyeing wastewater was discharged along with colorless stream of "washing after fixing". These revelations indicated the improper utilization of stream segregation facility. Appropriate stream segregation strategy with respect to wastewater analysis was studied in laboratory by preparing three wastewater samples from actual dyeing process effluents.

Analysis and names of effluents streams of dyeing process for colored and colorless samples are presented in Table 2. Experimental results showed that 36.4% of total wastewater during sweater dyeing can be segregated for

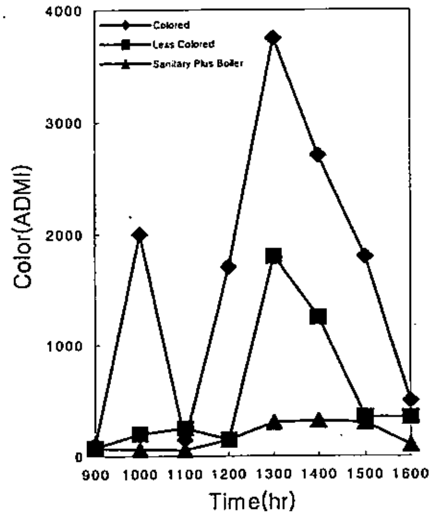

Figure 4. Variation of color in wastewater flow channels.

having minor contribution for COD and color of 130 mg/L and 30 ADMI respectively. The rest 63.6% wastewater is colored with high COD and color of 1295 mg/L and 3186 ADMI. Similarly for yarn dyeing, 46.2% of total wastewater is obtained in the form of colorless stream with COD and color of 155 mg/L and 21 ADMI while the remaining 53.8% wastewater have COD and color of 2690 mg/L and 2811 ADMI respectively. Experimental results showed that overall wastewater without stream segregation is of high color and COD values producing more volume for treatment.

In the case of yarn dyeing, the quantity of colorless wastewater stream was more than that of sweater dyeing due to "Fixing" step of dyeing process as fixing discharges were of low color and low COD values (Fixing is done for black, blue, coral and some other colors for both yarn and sweaters). Fixing step of dyeing process affects the quantity of colorless wastewater. It was assumed that fixing was done for 50% of the dyed products. Therefore, colorless wastewater can be quantified as 41% {(36.4+46.2)/2} of dyeing process effluents. Table 3 compares the quality of existing less colored wastewater stream with that of colorless wastewater obtained after proper stream segregation.

Table 2. Effect of stream segregation on wastewater quality during sweater and yarn dyeing

Type of waste-water	Est. W.W. quantity (m^3/L)	pH	Turbidity (NTU)	Conductivity (ms/cm)	Alkalinity (mg/L as $CaCO_3$)	TS (mg/L)	SS (mg/L)	COD (mg/L)	Color (ADMI)
For sweater dyeing									
Colored (a)	24.5 (63.63%)	12.1	0.05	9.40	1650	32.492	108	1295	3186
Colorless (b)	14.0 (36.36%)	8.9	3.0	1.10	450	780	18	130	30
Combined (c)	38.6 (100%)	11.3	0.1	6.10	1240	4472	92	865	3159
For yarn dyeing									
Colored (a)	9.80 (53.84%)	10.9	0.1	33.90	5000	22.968	434	2690	2811
Colorless (d)	8.40 (46.15%)	6.9	1.0	1.01	210	780	80	155	21
Combined (c)	18.20 (100%)	10.7	0.55	20.90	3000	14.372	364	1680	1929

(a) = Scouring W.W. + Washing after Scouring + Dyeing W.W. + Washing after Dyeing + Washing with formic acid + Washing with hot water
(b) = Formic acid and enzyme W.W. + Washing with water (after hot water) + Softening W.W.
(c) = Mixing wastewater discharged during each step
(d) = Formic acid and enzyme W.W. + Washing with water (after hot water) + Washing after Fixing + Softening W.W.

Table 3. Comparison of colorless wastewater before and after proposed segregation

Description of wastewater	pH	TS (mg/L)	SS (mg/L)	COD (mg/L)	Color (ADMI)
Current less colored wastewater stream	9.0	4658	76	333	1033
	9.5	5524	98	300	328
Proposed colorless wastewater stream after segregation	6.93	780	80	155	21
	8.85	772	18	130	30

The effect of proper stream segregation is pronounced from the comparison.

Filtered water was used for indirect cooling of yarn dyeing equipment. Waste audit pointed out that this cooling water neither follow any flow channel nor is recovered for reuse. Cooling water and filtered water have almost the same quality except temperature, which is a practical barrier in cooling water reuse.

Wastewater Treatment

Wastewater treatment was carried out for the combined wastewater and for colored wastewater obtained after segregation. Colored wastewater after treatment was mixed with colorless wastewater according to actual ratio as obtained after stream segregation between colored and colorless wastewater in order to see the overall reduction in COD and color. Following three types of treatment methods were used for the treatment of both kinds of wastewater; (i) Treatment using ferrous sulfate. (ii) Treatment using ferrous sulfate and lime. (iii) Treatment using Fenton's Reagent (ferrous sulfate and hydrogen peroxide). Anionic polyacrylamide flocculant was used as coagulant aid. Coagulation followed by flocculation was carried out to remove the color.

Ferrous sulfate alone and ferrous sulfate with lime gave significant reduction in color and COD. Optimum dose of ferrous sulfate was found as 1000 mg/L with 90.86% reduction in color and 45.16% reduction in COD. COD and color reductions were increased when lime was used along with ferrous sulfate. 54.84% reduction in COD and 95.10% reduction in color were found for optimum doses of 800 mg/L of ferrous sulfate and lime.

Treatment study of combined wastewater using Fenton's reagent was completed in three cycles of experiments. During first cycle ferrous sulfate doses were fixed at 300 mg/L while hydrogen peroxide doses were varied from 200 to 700 mg/L. During this cycle about 92% reduction in color was found but COD reduction was very low. During the second cycle ferrous sulfate doses were increased and fixed at 600 mg/L while hydrogen peroxide doses were varied from 200 to 700 mg/L. In this cycle of experiments 67.74% reduction in COD and 98% reduction in color were found for ferrous sulfate and hydrogen peroxide doses of 600 mg/L and 400 mg/L respectively. In third cycle of experiments hydrogen peroxide doses were fixed on 400 mg/L and ferrous sulfate doses were varied from 400 to 800 mg/L. In this cycle again 600 mg/L of ferrous sulfate with 400 mg/L of hydrogen peroxide gave maximum reduction in color and COD. Therefore, these doses were selected as optimum doses. Overall results of different treatment methods are given in Table 4. Treatment study shows that color reduction is more than 90% in all three methods but treatment with Fenton's reagent gave maximum COD reduction of 67.74%.

For colored wastewater, ferrous sulfate gave 84.62% reduction in color and 69.45% reduction in COD for an optimum dose of 1400 mg/L. But 91.72% color and 77.76% COD reductions occurred for optimum doses of 1200 mg/L of ferrous sulfate in conjunction with lime. Treatment study of colored wastewater with Fenton's reagent was completed in three sets of experiments. 800 mg/L of ferrous sulfate with 600 mg/L of hydrogen peroxide were found to give maximum COD and color reductions of 79.48% and 97.17% respectively. These doses were selected as optimum. Overall treatment efficiency of colored wastewater and analysis of the mixtures of treated colored wastewater with segregated colorless waste-

Table 4. Experimental results of physico-chemical treatment using different chemicals for combined wastewater

Chemicals used	Dosages (mg/L)	pH	TS (mg/L)	SS (mg/L)	Color (ADMI)	COD (mg/L)
Before Treatment		9.65	2776	63	1182	310
Ferrous Sulfate[a]	1000	9.21	1324	44	108 (90.86)[b]	170 (45.16)[b]
Ferrous Sulfate + Lime	800 + 800	9.53	2672	34	58 (95.10)[b]	140 (54.84)[b]
H_2O_2 + Ferrous Sulfate	400 + 600	7.30	1532	28	24 (97.97)[b]	105 (66.13)[b]

[a] Anionic polyacrylamide flocculant: dosage is 2 mg/L
[b] Percentage reduction

Table 5. Results of physico-chemical treatment using different chemicals for wastewater after segregation

Type of wastewater	Chemical dosages (mg/L)	pH	TS (mg/L)	SS (mg/L)	Color (ADMI)	COD (mg/l)
Colored Wastewater after Segregation	-	10.24	12263	174	1196	720
Colorless Wasterwater after Segregation	-	8.54	700	52	28	110
Ferrous Sulfate Treated Wastewater	1400	8.96	3200	143	184	220
Ferrous Sulfate + Lime Treated Wastewater	1200 +1200	9.36	3184	130	105	160
Mixture of Ferrous Sulfate Treated and Colorless Wasterwater	-	8.90	1635	82	94 (91.14%)[a)]	180 (75.00%)[a)]
Mixture of Ferrous Sulfate + Lime Treated and Colorless Wasterwater	-	8.82	1456	72	62 (94.81%)[a)]	130 (81.95%)[a)]

[a)] indicates overall reduction in colored wastewater after segregation

Table 6. Results of colored wastewater treatment using Fenton's reagent after segregation

Type of wastewater	Chemical dosages (mg/L)	pH	TS (mg/L)	SS (mg/L)	Color (ADMI)	COD (mg/L)	BOD (mg/L)
Colored Wastewater after Segregation	-	10.6	3628	126	389	780	360
Colorless Wastewater after Segregation	-	7.7	524	16	22	90	70
H_2O_2+Ferrous Sulfate Treated Wastewater	600+800	7.4	1743	41	11	160	110

water (in a ratio of 60 to 40% respectively) are presented in Tables 5 and 6.

CONCLUSIONS

1. Production schedule of dyeing is arranged on the basis of immediate requirement and no consideration is given towards the production planning with respect to light and dark colors. Uncertain coloring schedule results shock coloring load on the wastewater treatment facilities.
2. Waste audit study revealed that the major portion of water supply is consumed in dyeing process. Water balance indicates that 85% of total water supply, of which 70% coming directly from dyeing activities, requires further treatment. Wastewater from dyeing process is alkaline and its temperature is more than 50℃. BOD/COD ratio of the wastewater confirms the suitability of physico-chemical treatment.
3. Dyeing process has the potential of reducing wastewater treatment load by proper stream segregation. 42% of dyeing wastewater can be segregated as colorless non-polluting stream after implementation of proper stream segregation strategy and wastewater treatment facilities can be reduced to 55% of total water input. Cooling water used for

yarn dyeing can be reused just by lowering its temperature.

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