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Water and Chemical Management Studies for Cleaner Production in a Textile Industry

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In this study, environmental performance of a textile mill employing fiber production and subsequent dyeing was evaluated in detail. Cleaner production assessment studies based on Integrated Pollution Prevention and Control (IPPC) principles were conducted. Specific water and chemical consumptions in wet processes were calculated using mass balance analysis. The potential wastewater and/or chemical recovery and reuse options were determined. A company-wide chemical inventory study was conducted and the chemicals were evaluated in terms of their toxicological effects. It was found that a total of 29 chemicals should be replaced with less toxic and more biodegradable counterparts. By the application of suggested cleaner production options, the potential reductions in water and chemical consumptions and wastewater generations were determined. After the implementation of good management practices, wastewater recovery and reuse, machinery modifications, and chemical optimizations/replacements, the following reductions could be achieved; water consumption: 35-67 %, chemical consumption: 25-51 %, total wastewater flowrate: 37-70 %, COD load: 44-58 %. Thus, about 51 and 32 % savings could be achieved for water/wastewater and chemical costs. It was found that by the application of various suggested cleaner production techniques the pay-back periods of such investments range from 4 to 36 months.

1. Introduction

Textile industry consists of heterogeneous and long chain production units (EC, 2003). Dyeing and finishing processes consume vast quantities of water and chemicals in textile industry as can be seen from (Rosa et al., 2013) presenting a neural network model and from (Caselatto et al., 2014) looking into technological options. Typical water consumption in the sector is 20-350 L/kg product (Gozalvez et al., 2008). Typical chemical consumption in dyeing-finishing processes is 10-100 % of the fiber weight (Ozturk et al., 2009). The main environmental concern for the textile industry is the wastewaters with high flowrates and pollutant loads (Rosa et al., 2013; Spina et al., 2014). Textile wastewaters generally contain surfactants, dyes, pigments, resins, chelating agents, dispersing agents, inorganic salts, heavy metals, biocides, etc. (EC, 2003). Therefore, they are heavily loaded with chemical oxygen demand (COD), color and especially salts (Gozalvez et al., 2008). Inadequately treated textile effluents may thus cause major environmental impacts (Caselatto et al., 2014). More stringent discharge regulations, increasing costs for process water production and wastewater treatment appear to be major drivers for wastewater recovery and reuse in the sector. In addition, the textile sector also started to employ cleaner production technologies especially in the last 20 y. By the application of such techniques/technologies, the industrial sector may improve production efficiency, reduce raw material consumption and minimize waste generation. All these efforts inevitably enhance environmental and economic performance of the industries (EC, 2003).

The main objective of this work was to evaluate the technical and environmental performance of a textile mill employing fiber production and dyeing-finishing. Cleaner production assessment studies were

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conducted considering IPPC principles. The main focus was given to water and chemical usage in the mill. Specific water and chemical consumptions in wet processes were calculated using mass balance analysis. Wastewater samples from all sources of the production processes and composite wastewater were collected during 2 months of operation. Based on the water quality analysis of all wastewater streams, potential wastewater recovery and reuse options (with or without treatment) were assessed. A company-wide chemical inventory study was conducted and the chemicals were evaluated in terms of their acute and chronic toxicity, biodegradability and bioaccumulation. Cleaner production approaches were determined to obtain reductions in water and chemical consumptions and wastewater flowrates and loads. Furthermore, by the implementation of such approaches, potential technical, environmental and economic benefits were estimated. The major aims of the study to be road map of cleaner production assessment and technical/environmental performance evaluations of similar textile mills and sector stakeholders. Additionally, Turkey, which is a European Union candidate and one of the most important textile suppliers in Europe, has initiated the Integrated Pollution Prevention Control/Industrial Emissions Directive (IPPC/IED) adaptation process. This study will significantly contribute to the harmonization process of IPPC/IED.

2. Materials and methods

2.1. Studied textile mill

The studied textile mill produces hand knitting and carpet yarn in its production facility located in the City of Isparta, Turkey. The yarns produced by the mill are of different kinds including acrylic (PAC), polyester (PES), cotton (CO), polyamide (PA), wool, etc. Total annual yarn production and dyeing capacity are approximately 4560 and 2690 t, respectively. The production in the mill is heterogeneous due to various production types and hundreds of different dyeing protocols. Forms of hank yarn and raw fiber are dyed by dyeing and yarn printing machines. Dyeing operations are carried out by HT machines (high temperature/pressure), hank dyeing machines (high temperature/pressure for dyeing hank yarn), yarn spray printing-dyeing machines (LP), and yarn printing-dyeing machines (VP). Groundwater is softened by ion-exchange units employing cationic resins in the mill. Softened water is used in dyeing processes, steam boiler units, ion-exchange resins regeneration operation. Groundwater is used only in facility cleaning and drinking water is consumed for domestic usage in the mill. Generated wastewater from various units is collected through the open channel system. Domestic wastewater of the mill is collected separately. Industrial and domestic wastewater are combined in basin and discharged to municipal sewage system. Wastewater and chemicals recovery/reuse implementations are not used in the mill. Various recipes are prepared for yarn dyeing and printing processes depending on the types of fibers.

2.2. Data collection and evaluations

In the first phase of the study, on-site investigations were performed in the mill for about four weeks and detailed wet processes analysis was done based on the water and chemicals consumptions. All necessary data on production inputs (water, auxiliary chemicals, dyestuff etc.) and outputs were collected for 2010-2012 period. Groundwater and softened groundwater samples were collected. The samples were analyzed for various parameters including pH, conductivity, hardness, total organic carbon (TOC), total dissolved solid (TDS), turbidity etc. Wastewater samples from all sources of the production processes were also collected. From all these sampling points, a total of three sample sets was collected in different periods during two months to represent different dyeing recipes. These samples were analyzed for various parameters including COD, total suspended solid (TSS), total nitrogen (TN), color, conductivity, pH etc., employing the relevant Standard Methods (APHA, 1997). COD analysis was performed according to Standard Method 5220-D (closed reflux colorimetric method) using Hach-Lange DR5000 spectrophotometer. TN was measured spectrophotometrically according to Standard Method 4500-N-B (persulfate digestion method). TSS was analyzed using gravimetrically method (Standard methods 2540-D). Glass-fiber filters were used for TSS analyses. Color measurements were determined using Hach-Lange DR5000 spectrophotometer according to Standard Methods 2120-B (visual comparison method). Composite samples (2 h) were collected mostly in duplicate. Furthermore, analytical measurements of each sample were conducted in triplicate. In addition, a chemical inventory study was also conducted and material safety data sheets (MSDS) of approximately 340 chemicals were evaluated, especially based on biodegradability and toxicity (LC_{50}, LD_{50}, IC_{50}, and EC_{50}) aspects.

In the second phase of the study, mass balance analysis was performed. Specific water, chemicals and pollutant loads for discharges were calculated. It should be noted that the production schedule and dyeing recipes in the studied mill may vary by time based on fashion trends and customer orders. To compensate these variations and capture the general performance of the mill, three years of continuous data (2010-

2012) was used. Overall performance of the mill was determined and it was compared with those similar mills and European Commission Integrated Pollution Prevention and Control Best Available Techniques (IPPC BREF) Textile Document and communiqué of Integrated Pollution Prevention and Control in Textile Sector (Turkish BREF).

In the third phase of the study, cleaner production techniques were determined and discussed with the mill management in terms of techno-economics and practical applicability. Identified cleaner production techniques were evaluated in terms of potential environmental and economic benefits. Potential pay-back periods of the techniques were calculated.

3. Results and discussion

3.1. Evaluation of environmental performance

3.1.1. Water consumption and wastewater generation

Water demand of the textile mill was supplied by groundwater (97 %) and municipal drinking water grid (3 %). A share of 95 % of the groundwater was softened by ion-exchange units employing cationic resins. The main water consuming points in the mill were dyeing-finishing processes, steam generation, tank and facility cleaning, regeneration of the ion-exchange resins and domestic usage. It should be underlined that 70 % of the water consumption was due to the finishing-dyeing and printing processes. Continuous techniques were applied by 10:1 flotte ratio in HT dyeing-finishing process. Furthermore, decreasing the flotte ratios by various techniques (e.g. air-bag system) and condensate reuse have already been applied. Major factor of the high share of this process in overall water consumption was due to the share of itself (67 %) in overall production. High water consumption in hank dyeing-finishing processes was mainly due to the high flotte ratio (30:1), absence of condensate reuse and processing of hank wool fibers (high numbers of bath/long process chains). Finishing operations (washing/rinsing and softening) of yarns in LP and VP processes were conducted in hank dyeing machinery. Thus, significant amounts of water were consumed in LP-VP finishing processes. Steam generation have significant share (16 %) in overall water consumption. The main reason of this high consumption was due to the loss of generated steam, absence of condensate reuse and usage of semi-open steam system in the mill. Specific water consumption values of the mill were calculated on the basis of all production processes (Table 1). Accordingly, specific water consumption of the mill was in the range of 39-86 L/kg product. It is reported in the literature that similar dyeing-finishing mills have specific water consumption values in the range of 35-200 L/kg product (IEE, 2006; Kant, 2012). IPPC BREF document was indicated that the specific water consumption range of PAC and wool dyeing-finishing process is between 43-212 L/kg product (EC, 2003). Accordingly, it is indicated that even mill’s specific water consumption was in the determined ranges it could potentially be decreased by 10-59 %. High conductivity and hardness values in process water might lead to defects of dyeing, scaling and corrosion in steam/water grid and excessive chemical consumption. According to the analyses results, TDS, conductivity and TOC values were shown a slight increase in process water due to the ion-exchange process. Thus, it was understood that optimization of water softening system is needed.

Table 1: Specific water consumptions and their distributions based on the wet processes in the mill

Sources of water consumption	Average specific water consumption (min.-max.)	Percent of water consumption (%)
Raw water (L/kg product)	57 (39-86)	100
Facility cleaning (L/m^2-d)	1.5	5
Process water (L/kg product)	54 (36-84)	95
HT dyeing-finishing (L/kg product)	18 (10-30)	21
Hank dyeing-finishing (L/kg product)	115 (86-215)	22
LP printing-dyeing (L/kg product)	34 (27-40)	6
LP-VP finishing (L/kg product)	60 (30-90)	21
Steam generation (L/kg product)	9 (8-13)	16
Ion-exchangers regeneration (L/kg product)	6 (5-7)	9
Domestic usage (L/person-d)	32	-[a]

[a]*Drinking water used only for domestic usage in the mill*

It was found that 79 % of the wastewaters were generated from finishing, dyeing and printing processes. 11 % and 6 % of the overall wastewater was generated by regeneration of the ion exchange resins and facility cleaning, respectively. Share of HT, hank dyeing-finishing, LP printing-dyeing, LP-VP finishing processes were 24 %, 25 %, 6 %, and 24 %, respectively. Composite wastewater of the mill met the discharge regulations and discharged to the sewer without treatment. Average composite wastewater flowrate (except municipal wastewaters) of the mill was 420 m^3/d (min-max flow: 283-641 m^3/d) and average specific composite wastewater generation was 48 L/kg product (32-75 L/kg product). Composition and flowrate of the composite wastewater of the mill were continuously variable during the daily operation period. pH, conductivity, COD, TSS and color parameters of collected samples were analyzed. Thus, recovery/reuse potentials of process wastewaters were evaluated (Table 2).

Table 2: Wastewater characterization and evaluation of reuse potentials based on wet processes

Sample No.	Process	Fiber type	Color shade	pH	Conductivity (µS/cm)	COD (mg/L)	TSS (mg/L)	Color (Pt-Co)	Reuse potential
1	HT, dyeing	Wool	Dark	6.4	2230	1,584	66	2,255	WT[b]
2	HT, washing	Wool	Dark	6.7	1080	487	27	574	WT
3	HT, softening	Wool	Dark	6.6	1576	909	46	968	WT
4	HT, dyeing	Wool	Light	-[a]	-	-	-	-	Not evaluated
5	HT, washing	Wool	Light	-	-	-	-	-	Not evaluated
6	HT, softening	Wool	Light	-	-	-	-	-	Not evaluated
7	HT, dyeing	PAC	Dark	7.2	1059	674	8	576	WT/DR
8	HT, washing	PAC	Dark	7.8	641	299	12	244	WT/DR
9	HT, softening	PAC	Dark	4.9	682	5,056	220	1,790	WT
10	HT, dyeing	PAC	Light	4.5	1858	1,668	36	570	WT
11	HT, washing	PAC	Light	4.9	1169	2,576	5	266	WT/DR
12	HT, softening	PAC	Light	6.0	849	1,895	12	287	WT/DR
13	Hank, dyeing-1	Wool	Dark	4.6	960	2,040	55	890	WT
14	Hank, dyeing-2	Wool	Dark	4.5	989	2,024	10	381	WT/DR
15	Hank, washing	Wool	Dark	7.7	454	434	56	1,300	WT
16	Hank, softening	Wool	Dark	6.9	548	120	5	225	DR
17	Hank, dyeing-1	Wool	Light	4.8	1214	2,250	5	125	WT/DR
18	Hank, dyeing-2	Wool	Light	4.7	1198	2,350	7	178	WT/DR
19	Hank, washing	Wool	Light	7.5	462	2,152	93	2,210	WT
20	Hank, softening	Wool	Light	7.4	557	136	6	326	DR
21	LP, washing	PAC	Multi	7.9	451	10	1	126	DR
22	VP, washing	PAC	Multi	7.9	449	9	1	38	DR
23	VP, softening	PAC	Multi	5.0	605	4,000	15	122	WT/DR

**Analyze results on March 2013 [a]Data not available [b]WT: reused with treatment [c]DR: directly reused (without treatment)*

In this context, reuse criteria (pH: 6-8, conductivity <2200 µs/cm, COD <218 mg/L, TSS <50 mg/L and color 20-30 Pt-Co) of textile wastewaters in literature were generally adopted (Uzal, 2007). Since softening wastewaters (samples 16, 20) of wool fibers (light-dark color shade) in hank dyeing-finishing processes met the reuse criteria they could be reused in this process without treatment. Wastewaters from LP-VP finishing processes (samples 21, 22 and 23) could also be reused in dyeing-finishing processes without treatment. 5 dyeing wastewater streams (samples 4, 7, 14, 17, and 18) could be reused without treatment. Wastewaters from dyeing-finishing processes have high conductivity, COD, TSS, and color concentrations. Ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) processes could be employed for wastewaters (samples 1, 2, 3, 5, 6, 8, 9, 10, 11, 12, 13, 15 and 19) and further reused in dyeing-finishing processes. On the other hand, some washing and softening wastewaters (samples 8, 11 and 12) could be reused in dyeing-finishing processes after appropriate treatment or used in facility cleaning without treatment. Regeneration wastewaters could effectively be used in facility cleaning without treatment or reused in dyeing-finishing processes after RO treatment. COD, TSS, oil-grease, TN, TP analyses were performed in composite wastewater samples and specific pollutant load was calculated. According to this, specific loads of COD, TSS and oil-grease parameters were 48, 5 and 8 g/kg-product, respectively. Specific COD loads of HT and hank dyeing-finishing processes were 33 and 151 g/kg product, respectively. It is calculated that the specific COD loads of LP printing-dyeing and LP-VP finishing processes were 0.7 and 12 g/kg product, respectively. Thus, share of HT, hank dyeing-finishing and LP-VP finishing processes in COD load of composite wastewaters were 55 %, 38 % and 6 % respectively. Contribution of LP printing-dyeing processes to COD load of composite wastewater was only 1 % because of the low COD concentration and wastewater generation. Minimization of water consumption could be achieved in hank dyeing-finishing process by machinery modifications (reduced flotte ratios, reuse of condensate) and wastewater recovery/reuse applications. The main reason of the high specific water consumption in LP-VP processes was the high flotte ratio (30:1) of finishing operations. Three options could be employed for the minimization of water consumption: reuse of wastewaters, application of HT process (10:1) in LP-VP finishing processes instead of hank dyeing machinery (30:1) by manufacturing schedule revision and utilization of efficient batch-type washing machines. Furthermore, prevention of steam and condensate losses was in critical importance for steam generation system in order to minimize overall water consumption. In this context, there was a need for process-based monitoring of water consumption, use of automatic shut-off valves in continuously working machinery, preparation of annual inventory reports based on mass balance, implementation of preventive maintenance and repair works, employing efficient cleaning procedures, developing novel techniques in processes (first-time-right dyeing, use of combined processes), focusing on staff training and developing of cleaner production procedures.

3.1.2. Chemical consumption

Specific chemical (dyestuff and auxiliaries) consumptions and their distributions were determined based on the wet processes (Table 3). Accordingly, dyestuff consumption was intensive in HT dyeing-finishing (49 %) and LP printing-dyeing processes. Moreover, auxiliaries consumption were more intensive in hank (34 %) and HT (28 %) dyeing-finishing processes in the mill. High chemical consumption in hank dyeing-finishing process was mainly due to high flotte ratio (30:1) and processing of hank wool fibers. Printing techniques (spray/degrade and transfer printing) were applied in LP and VP printing-dyeing processes and finishing operations of yarns were conducted in the hank dyeing machinery by high flotte ratio. According to Table 3, specific dyestuff and auxiliaries consumption in the mill were calculated as 13-16 and 133-167 g/kg product, respectively. It is reported in the literature that similar textile mills have specific dyestuff and auxiliaries consumption values in the range of 3-110 and 63-1776 g/kg product, respectively (Kalliala and Talvenmaa, 2000; IEE, 2006). IPPC BREF document was indicated that the specific dyestuff and auxiliaries consumption in similar textile mills which makes yarn dyeing-finishing ranged from 13-26 and 58-428 g/kg product, respectively (EC, 2003). Also, specific dyestuff and auxiliaries consumption of PAC and wool fibers dyeing-finishing process was between 13-18 and 121-415 g/kg product, respectively. Hence, dyestuff and auxiliaries consumption could potentially be decreased by 6-9 % and 9-65 %, respectively. Manual techniques were applied by the mill for the preparation and dosing of chemicals. Thus, significant amounts of chemical were lost. In this context, installation of automatic dosing system, revised production programs, optimization of recipes, chemical recovery by the reuse of wastewater, increasing of coordination between dyehouse and laboratory and various good management practices are needed. In addition, chemical inventory studies were performed. Approximately 340 dyestuff and auxiliaries MSDSs were studied. According to the studies, 29 chemicals were determined which have lower biodegradability rate (<70 %) and highly toxic (<0.1 mg/L), and toxic character (1-10 mg/L) for the eco-toxicity (LD_{50}, LC_{50}, EC_{50} and IC_{50}). In this context, 29 chemicals designated in the mill were required to replace with environmental friendly substitutes.

Table 3: Specific chemicals consumptions and their distributions based on the wet processes in the mill

Process	Average specific dyestuff consumptions (min.-max.) (g/kg product)	Average specific auxiliaries consumptions (min.-max.) (g/kg product)	Percent of dyestuff (%)	Percent of auxiliaries (%)
HT dyeing-finishing	10 (10-11)	62 (54-69)	49	28
Hank dyeing-finishing	11 (9-13)	447 (420-470)	8	34
LP printing-dyeing	46 (39-52)	400 (336-453)	31	26
VP printing-dyeing	17 (14-19)	170 (125-203)	12	12
Total	15 (13-16)	150 (133-167)	100	100

3.2. Evaluation of environmental and economic benefits

Potential savings were calculated by the application of cleaner production techniques in the textile mill (Table 4). After the implementation of cleaner production techniques, the following reductions could be achieved; water consumption: 37-72 %, total wastewater flowrate: 39-75 %, COD load: 46-61 %. However, application of different cleaner production techniques might result in various interactions between potential savings. In this case, about 35-67 %, 37-70 %, 44-58 % savings could be achieved for water consumption, total wastewater flowrate and COD load, respectively. Besides, savings of about 21-43 % could be achieved in chemical consumption. About 51 and 32 % savings could be achieved for water/wastewater and chemical costs. It was found that the pay-back periods of such investments range of 4-36 months.

Table 4: Calculated savings and reductions rates for each cleaner production techniques in the mill

Cleaner production techniques	Water saving rate (%)	Chemical saving rate (%)	Wastewater reduction rate (%)	COD load reduction rate (%)	Pay-back period (months)
Good management practices	3-5	2-5	3-6	-[a]	4-12
Reuse of waste dye bath	7-8	7-18	7-9	8-9	13-20
Reuse washing/rising and softening wastewater	16-41	3-8	18-43	31-40	4-26
Washing/rising wastewater reuse for cleaning facility and ion-exchangers optimization	6-8	-	6-7	3-4	4-10
Reduce to flotte ratio of hank dyeing machines	2-5	4-8	2-5	2-3	24-36
Recovery condensate and steam optimization	3-5	-	3-5	-	4-18
Recipes optimization, chemicals substitution, automatic dosage system installation	-	9-13	-	2-5	24-36
Total reductions/benefits	37-72	25-51	39-75	46-61	-
Effective reductions/benefits	35-67	21-43	37-70	44-58	4-36

[a]*Data not available*

4. Conclusions

Environmental and technical performance of a textile mill employing fiber production and subsequent dyeing was evaluated in detail. Based on EU IPPC Textile BREF and Turkish Textile BREF documents, a list of cleaner production techniques for water and chemical usages was suggested to the mill. It was found that some separate wastewater streams from dyeing-finishing processes may be directly reused in these processes even without treatment. A company-wide chemical inventory study indicated that a total of 29 chemicals should be replaced with less toxic and more biodegradable counterparts. After the implementation of suggestions, the following reductions could be achieved; water consumption: 35-67 %, chemical consumption: 25-51 %, total wastewater flowrate: 37-70 %, COD load: 44-58 %. Thus, about 51 and 32 % savings could be achieved for water/wastewater and chemical costs. It was found that by the application of various suggested cleaner production techniques the pay-back periods of such investments range from 4 to 36 months.

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