Chapter 9
Wastewater Reuse in Textile Industry

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Abstract Current understanding of industrial pollution control attributes significant attention to in-plant control measures targeting mainly waste minimization at source. Accordingly only after realizing front-of-pipe prevention measures by the help of in-plant control activities, end-of-pipe treatment alternatives can be adopted. Wastewater reuse which is considered as an important part of in-plant control efforts gains special significance in textile industry due to the intense usage of water in the sector. While evaluating a textile plant for wastewater use alternatives a rational methodology covering technical and economical feasibility studies must be followed. Issues such as possible adverse effects on product quality or the end-of-pipe wastewater characterization must be addressed.

Keywords Wastewater • Reuse • Textile industry • In-plant control • End-of-pipe treatment

9.1 Introduction

According to the up to date understanding of industrial pollution control two issues come forward: The first one is about the scale of protection dictating the coverage of the entire environment rather than concentrating on a single media. Hence emissions to air, land and water must be controlled within an integrated industrial waste management policy. The second issue addresses the importance of manufacturing processes in pollution control efforts. Accordingly an industrial facility must adopt

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a stage-wise approach that tackles in-plant control measures prior to coping with an end-of-pipe treatment. European Council Integrated Pollution Prevention and Control (IPPC) Directive; and the US Pollution Prevention Act (PPA) [9, 19] are among the examples of legislation underlining the significance of in-plant control measures. Besides, environmental and ethical issues attract public attention nowadays. Therefore, the manufacturers are tending to improve their images through avoiding wasteful practices and applying reuse. Briefly a sound industrial waste management strategy requires the prevention of multimedia pollution via in-plant control measures followed by end-of-pipe treatment. In order to do so the following steps must be adopted in a stage-wise manner:

1. in-plant control

   water conservation
   wastewater reclamation and reuse
   material reclamation and reuse
   substitution of chemicals
   modifications and/or changes in processes and/or technologies

2. end-of-pipe treatment

When applying an in-plant control measure case specific issues must be considered. For example, the cost of fresh water in the region where the plant is located gains importance while evaluating a plant in terms of wastewater reclamation and reuse. A feasibility study covering both technical and economical issues must be conducted before adopting any kind of in-plant control measure. It should be kept in mind that not only many environmental benefits but also some financial inputs can be obtained by following such a management strategy.

Textile industry is among the most wide-spread manufacturing sectors in the world. The sector generates many products (carpet, knit fabric, yarn, hosiery, woven fabric, denim fabric, etc.) from a variety of raw materials (cotton, wool, natural polymers, jute, silk, linen, synthetic polymers such as polyester etc. and their blends) with the help of various types of equipment (jig, beck, package, thermosol, skein, pad-roll, jet, pad-steam etc.) operating under different modes (batch, semi-continuous or continuous). During the production an array of dyes from direct, disperse, acid, mordant, metal-complex to sulphur, basic, reactive together with a huge number of auxiliary chemicals (biocides, anti foaming agents, surfactants, carriers, flame retardants, leveling agents, softeners, lubricants etc.) can be used. Small and medium scale production facilities, some operating very dynamically to meet the immediate demands of market; as well as integrated large scale premises are manufacturing within textile wet processing sector. Such a variable and complex picture necessitates a case by case evaluation for the application of environmental measures.

Poor housekeeping practices leading to unnecessary water usage, missing the opportunities of valuable by-product recovery, inefficient operations causing the loss of expensive chemicals are the common pitfalls observed in textile mills. All of these examples can be solved by applying case specific in-plant control measures.

Textile wet processing can be characterized with high water usage that consequently leads to high wastewater generation. Although water consumption and wastewater generation levels as low as 20 m^3 ton^{-1} textile products are also reported in literature, the typical values are stated to be within a range of 200–400 m^3 ton^{-1} textile product [14, 16]. Such a high water requirement highlights the significance of wastewater reclamation and reuse applications among other in-plant control measures. Possible economical benefits triggers the efforts to adopt wastewater reuse in textile sector.

In the context given above the objective of this chapter is to present a wastewater reuse methodology applicable to textile wet processing industry.

9.2 Methodology to Achieve Wastewater Reuse in Textile Wet Processing

Industrial wastewater reuse is an in-plant control measure. Hence it requires a lot more effort devoted to the details of the production processes. In order to evaluate the applicability of wastewater reuse in an industrial premise a comprehensive analysis including a wide range of items from the auxiliary chemicals added during each step of the processes to the detailed characterization of the segregated wastewater streams must be performed. A stage-wise methodology for wastewater reuse is presented below:

9.2.1 Establishing Production Flowcharts

Production flowcharts developed to illustrate every step of the production processes with the help of boxes and arrows can be used as an information rich tool. An example production flowchart dealing with knit fabric finishing is illustrated in Fig. 9.1. All sorts of material movements i.e. inputs (from auxiliary chemicals to raw materials) and outputs (from products and by-products to wastes) must be tabulated in production flowcharts. If available the quantities related to the inputs and outputs have to be presented. Especially the quantities of water inputs and wastewater discharges must be inserted to production flowcharts. The reliability of the gathered data must be checked by conducting a simple materials balance. After such a check, the production flowcharts can be used as a solid source of information.

9.2.2 Assessment of Water Usage

The quantities of process water inputs are obtained from the production flowcharts. Apart from these inputs all other water requirements (i.e. for domestic purposes, cooling water make-up, boiler make-up etc.) must be tabulated. The quality requirements for these water usages must also be defined. For this purpose reuse criteria given in literature and/or the specific quality requirements of the manufacturer can be used. Due to the complex and variable nature of textile industry there is no

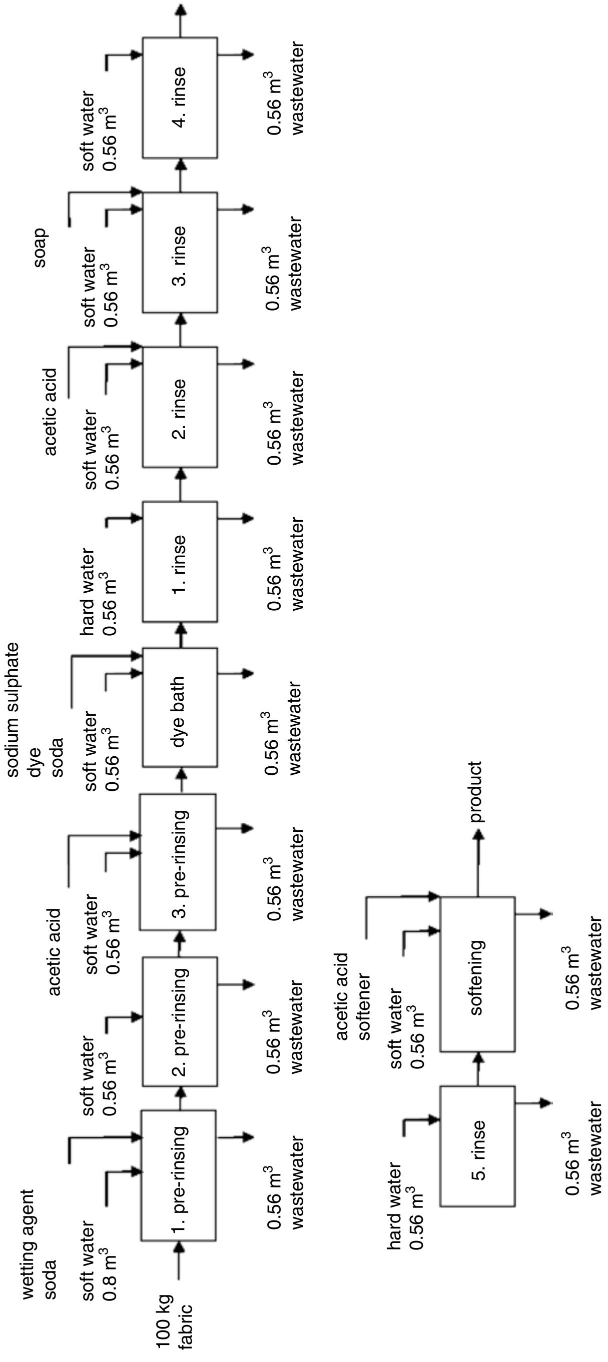

Fig. 9.1 Knit fabric finishing in overflow equipment [7]

Table 9.1 Reuse criteria applicable to textile process waters

Parameter	Li and Zhao [12]	Hoehn [11]	De Florio et al. [3]	Van der Bruggen et al. [20]	Unlu et al. [18]	Lu et al. [13]
Total COD (mg L^{-1})	0–160	<50	80	60	80	50
TSS (mg L^{-1})	0–50	<500	5	–	–	0
TDS (mg L^{-1})	100–1,000	–	–	–	–	–
Total hardness (mg $CaCO_3$ L^{-1})	0–100	90	2.5 (°F)	5 (°F)	–	–
Chloride (mg L^{-1})	100–300	<150	–	–	–	–
Total Chromium (mg L^{-1})	–	0.1	–	–	–	–
Iron (mg L^{-1})	0–0.3	0.1	–	0.1	–	–
Manganese (mg L^{-1})	<0.05	0.05	–	0.1	–	–
Conductivity (μS cm^{-1})	800–2,200	–	1,000	–	1,000	–
Alkalinity (mg $CaCO_3$ L^{-1})	50–200	–	–	–	–	–
TKN (mg L^{-1})	–	–	20	–	–	–
Turbidity (NTU)	–	–	1	–	–	2
TOC (mg L^{-1})	–	–	30	–	–	–
Color (Pt-Co)	–	–	–	–	20	10
pH	6.5–8.0	6.5–7.5	6–8	6.5–8	–	–

agreed upon reuse criteria applicable to process waters. Table 9.1 gathers reuse criteria given in literature. In some textile plants process waters having two different qualities (hard and relatively soft) are used as a feed for different processes. An example of such textile process is given in Fig. 9.1 [7].

9.2.3 Characterization of Segregated Effluent Streams

By referring to the established production flowcharts some of the segregated effluent steams must be selected for characterization. As the relatively clean discharges (effluent streams obtained from the process stages where no or very small amounts of auxiliaries are added; i.e. rinsings) have a reuse potential, such streams have to be characterized for pollutants.

Table 9.2 outlines reusable wastewater characterization obtained from three different textile plants. Plant 1 and 2 deal with cotton knit fabric manufacturing. In both of the textile mills optical brightening, peroxide bleaching and dyeing operations are performed by adding auxiliaries such as H_2O_2 and reactive dye. Plant 3 applies wool, polyester and wool/polyester blends woven fabric finishing operations. Softeners and crease proofing agents are used during processes.

9.2.4 Evaluation of Segregated Wastewaters

Segregated effluent quality and quantities must be evaluated by checking the quality and quantities of water requirements. In some cases segregated effluents are reused only after passing through a specific treatment to improve the quality.

The most commonly applied wastewater reuse measures adopted in textile mills can be discussed under two headings [21]: The first one involves the reuse of uncontaminated non-contact cooling water obtained from condensers, heat exchangers, yarn dryers,

Table 9.2 Characterization of untreated reusable wastewater streams

	Dogruel [4]	Orhon et al. [15]	Dulkadiroglu et al. [5]
Reference	Plant 1	Plant 2	Plant 3
Total COD (mg L^{-1})	315	350	180
Soluble COD (mg L^{-1})	190	200	120
TSS (mg L^{-1})	60	80	15
VSS (mg L^{-1})	60	80	ND
Color (Pt-Co)	30	25	20
Cl^- (mg L^{-1})	275	320	ND
TDS (g L^{-1})	1.18	1.1	0.34
pH	7.4	5.2	7.1
% Flow rate	52	22	34

Table 9.3 Characterization of end-of-pipe effluents before (B) and after (A) wastewater reuse

Reference	Plant 1[a]		Plant 2[b]		Plant 3[c]	
(mg L^{-1})	B	A	B	A	B	A
Total COD	955	1,220	1,180	1,475	690	1,460
Soluble COD	675	850	890	1,215	455	970
TSS	105	125	100	115	88	190
VSS	85	95	90	94	80	180
TKN	ND	ND	14	ND	20	ND
T-P	ND	ND	13	ND	0.8	ND
pH	6.5	9.7	10.3	10.6	7.1	6.2

[a] Dogruel [4]
[b] Orhon et al. [15]
[c] Dulkadiroglu et al. [5]

pressure dyeing machines, air compressors etc. in processes requiring hot water. The second one on the other hand is the reuse of process wastewater originating from one operation in another unrelated operation. The most common examples are [14, 21]:

1. reuse of wash water from bleaching operations in caustic washing and scouring;
2. direct reuse of cooling water;
3. reuse of mercerizing wash water for scouring, bleaching operations and for wetting the fabric;
4. reuse of scouring rinses for desizing;
5. reuse of final rinsing waters in bleaching for bath make up or primary rinsing baths.

The approval of the workers is needed if the reclaimed wastewater is going to be used for domestic purposes i.e. in toilet flushing. On the other hand if a part of the generated wastewater is used in production processes (as it is or after passing through a specific treatment defined for reusable effluent streams), an approval from the manufacturer is required. The key term at this stage is the product quality. The product quality has to be checked after reusing the segregated effluents in production. The possible negative effects detected can be avoided by improving the reused wastewater quality.

9.2.5 Technical and Economical Feasibility

By segregating the relatively less polluted wastewater streams as reusable effluents, a much stronger end-of-pipe effluent likely to cause troubles in treatment plant can be generated. The treatability of end-of-pipe wastewaters before and after the application of reuse must be compared with each other. Characterization of end-of-pipe effluent streams before and after wastewater reuse for the Plant 1, 2 and 3 are tabulated in Table 9.3. As expected a stronger end-of-pipe wastewater is obtained after reuse application. The important issue at this point is to assess the impact of reuse

Table 9.4 Biodegradability of end-of-pipe effluent before (B) and after (A) wastewater reuse

		Total COD (mg L^{-1})	Soluble inert COD (mg L^{-1})	Particulate inert COD (mg L^{-1})	Biodeg. COD/Total COD (%)
Plant 1[a]	A	955	320	ND	ND
	B	1,220	365	ND	ND
Plant 2[b]	A	1,180	247	63	74
	B	1,475	307	78	74
Plant 3[c]	A	690	32	72	85
	B	1,460	67	149	85

[a] Dogruel [4]
[b] Orhon et al. [15]
[c] Dulkadiroglu et al. [5]

on the biodegradability of the end-of-pipe effluent. The results of this investigation presented in Table 9.4 indicated that reuse application does not affect the biodegradability of the effluents originating from the plants under evaluation.

Furthermore segregated effluent streams might require a specific treatment prior to be reused. Treatability of reusable wastewater streams must be evaluated. A wide range of treatment schemes from activated carbon applications, ozonation to electrolysis and nanofiltration can be used for reclaimed textile effluents [1, 2, 6, 8, 10, 17].

An evaluation based on:

1. the savings obtained from lowering the freshwater input;
2. the additional investment and operation costs related to the installation and operation of new pipelines, pumping facilities etc.;
3. investment and operational costs arising from the possible pre-treatment requirement of the reclaimed wastewater before reuse;
4. possible elevation of the end-of-pipe treatment costs due to dealing with a more concentrated effluent can be used to get economical feasibility.

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