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Research Article

Reducing Energy and Water Consumption in Textile Dyeing Industry with Cleaner Production by Inlet-Outlet Modification to Reuse Wastewater

Erkata Yandri[1,2*], Rinaldi Idroes[3], Roy Hendroko Setyobudi[1,4], Carolus Boromeus Rudationo[1], Satriyo Krido Wahono[5], Rangga Kala Mahaswa[6], Juris Burlakovs[7], and Herry Susanto[1]

[1]Graduate School of Renewable Energy, Darma Persada University, Jl. Radin Inten 2, Pondok Kelapa, East Jakarta 13450, Indonesia
[2]Center of Renewable Energy Studies, Darma Persada University, Jl. Radin Inten 2, Pondok Kelapa, East Jakarta 13450
[3]Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Syiah Kuala, Kopelma Darussalam, Banda Aceh 23111, Indonesia
[4]Department of Agriculture Science, Postgraduate Program, University of Muhammadiyah Malang, Jl. Raya Tlogomas No. 246, Malang, 65145, Indonesia
[5]Research Division for Natural Product Technology – Indonesian Institute of Sciences, Jl. Jogja - Wonosari, km 31.5, Gunung Kidul, Special Region Yogyakarta 55861, Indonesia
[6]Faculty of Philosophy, Universitas Gadjah Mada, Jl. Olahraga, Caturtunggal, Depok, Sleman, Yogyakarta 55281, Indonesia
[7]Department of Water Management, Estonian University of Life Sciences, Tartu, Estonia; Friedrich Reinhold Kreutzwaldi 1a, 51014 Tartu, Estonia

Abstract: Dyeing Finishing (DF) textile industries which consume a lot of energy, chemicals, water, etc., then produce a lot of wastewater which creates significant environmental problems, can be anticipated by applying Cleaner Production. This paper is presented to discuss the technical modification process of dyeing production machines, which reuse process wastewater to save water and energy consumption in the production process. For that reason, there are three steps taken. First, understand the process flow of the textile dyeing industry. Second, understand in detail the dyeing process of the Jet Dyeing (JD) machine. Third, implement steps on the floor, focusing on the JD machine, starting from the initial conditions until the third step. As a result, savings in water consumption per day for 10 JD machines were achieved by almost 50 %, with details; at the initial status 700 000 L, 600 000 L in the first step, 430 000 L in the second step, and finally 400 000 L in the third step. A similar action can be carried out in other processes, such as washing, de-sizing, or in other industries which also consume a lot of water and energy.

Keywords: Energy Efficiency, Jet Dyeing, Waste and Water Management, Reuse Wastewater, Wastewater Treatment Plant, Water Efficiency.

1. INTRODUCTION

Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs [1]. To increase awareness of global environmental problems, it is expected the wisely utilization of natural resources from all parties and sectors [2]. As an important natural resource, water faces a serious problem for its availability and quality [3] The industrial sector contributes to a major consumer of clean water resources as well as produces a lot of wastewater

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*Corresponding Author: Erkata Yandri <erkata@gmail.com, erkata@pasca.unsada.ac.id>

[4]. The industry should always be assessed the environmental performance from process and product perspectives. The manufacturing sector interprets it as a process that requires fewer resources and no waste produced. Waste is an unwanted product or damage, defective during the manufacturing process.

Figure 1 shows the basic concept of action to reduce energy and water consumption [5]. As shown in Figure 1(a), to collect and interpret technological innovation, the data is distinguished between technical and organizational innovations. Technical innovations are divided into product and process. Process innovations focus to reduce input with a given amount of output. Product innovations improve goods and services by developing new goods. Organizational innovations apply to total quality management. Cleaner Production (CP) refers to process-related into end-of-pipe and integrated technologies.

As shown in Figure 1(b), CP defines as the continuous improvement to reduce the utilization of air, water, land, to prevent pollution and to reduce the waste generation in the process, products, and services, to improve the efficiency, better environmental performance, and increase competitive advantage. In short, CP is the continuous application of an integrated preventive environmental strategy to processes and products to reduce risks to humans and the environment [6]. CP encompasses a thorough review of all aspects of business operations and identifies opportunities where improvements will help the business's economy as well as the environment. CP avoids staff from undue accidents, increases the morale of staff, improves product compliance, prevents spills, and raises the business's image amongst competitors. CP also creates awareness for pollution, wastes and emissions.

Figure 1(c) shows a secondary source of waste generation as the excess energy required to process and treat any waste generated. In the manufacturing industry, there are three classes of waste. *Process wastes, the most costly waste:* are solid, liquid, vapour, and excess-energy-generated wastes from the lower-value feed materials to the higher-value products. *Utility wastes:* are solid, liquid, vapour, and excess-energy wastes from utility systems to support the process, such as steam, electricity, water, compressed air, waste treatment, etc. Other wastes: are the results from start-ups and shutdowns, housekeeping, maintenance, etc. The textile industry, especially Dyeing Finishing (DF) consumes a lot of resources, such as energy, chemicals, and water during the process and produces a lot of wastewater contributing to environmental issues [7]. CP can be applied for DF focusing on the wet process in the Jet Dyeing (JD) machine. Reduction of water consumption with CP will reduce both the energy cost and also chemical cost.

CP has been widely studied and applied to the dyeing process in the textile industry to reduce water consumption and environmental impact. Lu *et al.* [8] combined a treatment system with two-stage anaerobic-aerobic treatment, biological aerated filter process (BAF), and membrane technology, resulting in the highest efficiency in terms of removal efficiency for COD, colour, and turbidity. Cesar da Silva *et al.* [9], conducted a survey and expert analysis for more than 100 large textile industries to established with data analysis structural equation modelling for hypothesis testing. They determined that cleaner production could give a good impact on operational, environmental and economic performance, as same as result, the same result has also been obtained by de Oliveira *et al.* [10].

Haji *et al.* [11] reviewed the effect of plasma treatment on surface modification of most used natural and synthetic fibres and the effects using natural dyes provide to reduce wastewater and toxic chemicals for CP. Fauzi *et al.* [12] analyzed the strategy to implement the CP concept in a batik industry by waste identified the dyeing, soaking, and rinsing processes were main contributors to the dye waste and suggested using natural dyes to minimized water pollution. Cinperi *et al.* [13] used composite wastewaters to treat the quality of reuse wastewaters in a pilot-scale MBR process and resulted in the high purification efficiency of textile wastewater. Núñez *et al.* [14] evaluated the electrocoagulation for efficient removal of pollutants in the industrial liquid waste with some variables to remove 86 % colour, 82 % turbidity, and 59 % COD without a negative effect on the dyed fabric quality. Chiarello *et al.* [15] evaluated

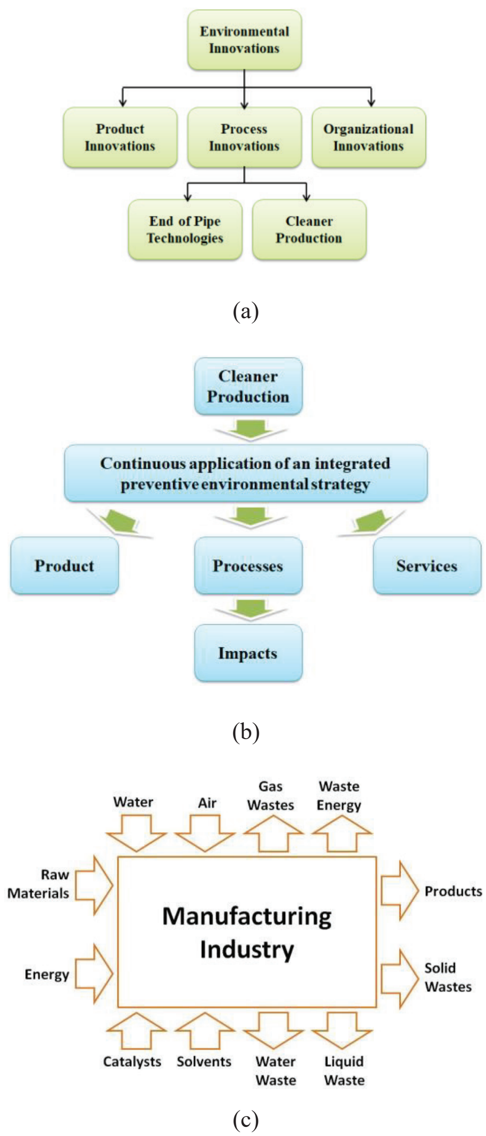

Fig. 1. The basic concept of action, a). From the Environmental Innovations to Cleaner Production, b). From the Cleaner Production to impacts, c). Basic input-output the manufacturing industry [5].

the number of reuse cycles of residual dyeing bath from reactive cotton dyeing treated with horseradish peroxide with 99 % colour removal. Forte and Prelog [16] evaluated the dye-house wastewater treatment with a flocculation method for re-use in further process, resulted in the high efficiency of dye-house wastewater treatment. Silva *et al.* [17] integrated two processes of a chemical-electrochemical oxidation process with a cationic exchange process using marine macro-algae, resulted successfully reused in other wet processes. Chen [18] evaluated the model of 10 indicators of advanced treatment technology for printing and dyeing wastewater with the analytical hierarchy process (AHP), resulted in good consistency for further process.

Based on the literature review above, CP has been widely carried out in the textile DF industry in all processes, with the aim of environment, efficiency, etc. Most of the studies focus on restoring the condition of wastewater by chemical or biological processes to become water that meets production requirements. These two processes become separate production units supported by sophisticated technology, which requires a high initial investment and higher water treatment costs. However, not many papers have discussed in detail the technical steps taken. Also, no publication discusses the reuse of dyeing production wastewater directly with modifications and specific process strategies easily, quickly, and cheaply. The purpose of this paper is to discuss the technical modification process in dyeing machines, which reuse process wastewater to save water and energy in the production.

2. MATERIALS AND METHODS

The method of research was based on the regular daily operational activities and floor observations in a textile dyeing finishing which process polyester and rayon fabric. There are several steps taken. First, understand the process flow of the textile dyeing industry. The textile industry is a very diverse sector in terms of raw materials, processes, products, and equipment. It can be categorized roughly into dry and wet processing. Dry processing includes yarn manufacturing, fabric weaving, and knitting. Wet processing is the most water, energy, and pollution-intensive, especially for cotton as natural fibre. Generally, the flow of the wet process for dyeing can be shown in Figure 2. The process of Singeing, de-Sizing, Washing, Boiling, and Bleaching is categorized as the Preparation process. Preparation aims to remove impurities and foreign matters, clean and modify the fabric for follow up processing or provide certain qualities for end-use. About half of the total pollution and a significant amount of wastewater from wet processing comes from preparation. The Dyeing process in the wet process to be the highest priority concern which may cause a major environmental problem with colour, BOD (10 % to 20 %), most metals, salts, COD (>30 %), high water and energy consumed [10]. Jet Dyeing (JD) machine is one of the popular for dyeing which consumes a lot of water. Environmental performance of the dyeing process is very much related to specific water and energy consumption, dyestuff fixation (%), liquid ratio (LR), heavy metals, use of environmentally hazardous chemicals, and shading.

Second, understand in detail the dyeing process of the JD machine. It was started from the analysis of the dyeing process by collecting data from each machine base on the individual step of the process, these included characteristics of colour processed by a JD machine, water required, and water wasted by the machine and the most important thing is the colour quality which only can get a result from Lab Dips.

Third, implement action on the floor. The actions are to understand the current process and status of water consumption. The first action was by utilizing the water used for cooling for the first dyeing process for a light colour. The second one was by utilizing the water used for Over Flow 2 (OF2) for the first dyeing process for a dark colour. The third one was by utilizing the water used for Over Flow 1 (OF1) for the first dyeing process of black colour.

3. RESULTS AND DISCUSSION

3.1 Pre-implementation

There are 10 Jet Dyeing (JD) machines with a capacity of 300 kg of raw fabric per batch for different processes and colour allocation. The daily dyeing output is 25 000 m. The standard ratio of water to the fabric from each JD is 7 L kg^{-1} to 10 L kg^{-1}, depending on the technology. The total water consumption per batch for 10 JD machines is about 199 015 L or about 600 000 L d^{-1} with 3.3 batches per machine d^{-1}. The details of step dyeing, colour allocation, and water consumption for each JD machine can be seen in Table 1. The washing step is as same as the dyeing process with additional cleaning using loop fabric and additional cooling. The total water consumed for cleaning 10 JD machines was 375 179 L. Since only 3.3 JD machines are washed daily, the water consumption is only 112 000 L. Table 2 shows the detailed step of washing and water consumption for each JD machine.

The first step of dyeing is dyeing itself which some dark colours can be started with hot water. To keep the stability of colour to be processed, each machine has a special task of colour. JD1, JD2, JD3 are used to process the light colour. JD4 is a small machine that is intended to be a re-process machine. JD5 is to process the medium colour. JD6 is to process the cationic colour. JD7 and JD8 are to process the dark colour. JD9 is to process the special colour and JD10 is to process the Black colour. JD1, JD2, JD3, JD6, JD7, JD8, JD9, JD10 have a set volume of water for 3 000 L $batch^{-1}$ and JD4 and JD5 have a set volume of water for 1 850 L $batch^{-1}$ and 7 000 L $batch^{-1}$.

Comparing to machines with the same capacity of dyeing, JD10 with the black colour processed consumed of water 63 191 L per batch, more water than the other JD machine except for JD4 with small capacity and JD5 with double capacity. Comparing to the process, the cooling process consumed 56 740 L of water for 10 JD machines, more than the other process. The total water consumed for

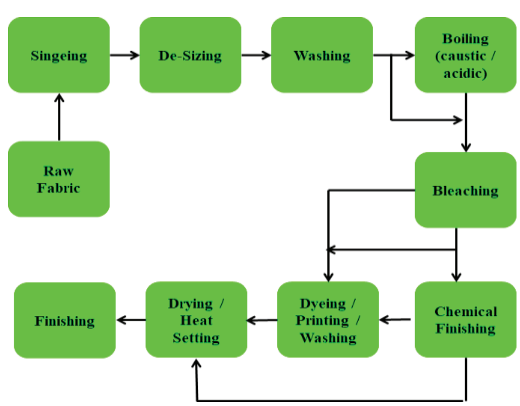

Fig. 2. General wet process flow of the dyeing [19]

Table 1. Step dyeing, colour allocation, and water consumption of JD machines per batch

JD	Process	Allocate	L batch^{-1}										
			Dyeing 1	Cooling	Over Flow 1	Filling Over Flow 2	Over Flow 2	Neutral	Over Flow 1	Filling Over Flow 2	Over Flow 2	Out	Total
1	Non RC	Light	3 000	4 149	700	3 000	1 000	-	-	-	-	3 000	14 849
2	Non RC	Light	3 000	4 149	700	3 000	1 000	-	-	-	-	3 000	14 849
3	Non RC	Light	3 000	4 149	700	3 000	1 000	-	-	-	-	3 000	14 849
4	1/2 RC	Repro	1 850	3 436	350	1 850	350	925	-	-	-	1 850	10 611
5	1/2 RC	Medium	7 000	13 000	5 000	7 000	5 000	3 500	-	-	-	7 000	47 500
6	Non RC	Cationic	3 000	5 571	1 000	3 000	1 000	-	-	-	-	3 000	16 571
7	RC	Dark	3 000	5 571	1 000	3 000	1 000	3 000	-	-	-	3 000	19 571
8	RC	Dark	3 000	5 571	1 000	3 000	1 000	3 000	-	-	-	3 000	19 571
9	RC	Special	3 000	5 571	1 500	3 000	1 000	3 000	-	-	-	3 000	20 071
10	RC	Black DB	3 000	5 571	2 000	3 000	1 000	3 000	3 000	3 000	1 000	3 000	20 571
Total			32 850	56 740	13 950	32 850	13 350	16 425	3 000	3 000	1 000	32 850	199 015

Table 2. Steps of washing process and water consumption for JD machines

JD	Process	Allocate	L batch^{-1}												
			Dyeing 1	Cooling	Over Flow 1	Filling Over Flow 2	Over Flow 2	Neutral	Looper	Cooling	Over Flow 1	Filling Over Flow 2	Over Flow 2	Out	Total
1	Non RC	Light	4 000	4 149	700	3 000	1000	3 000	3 000	4 149	700	3 000	1 000	3 000	30 698
2	Non RC	Light	4 000	4 149	700	3 000	1 000	3 000	3 000	4 149	700	3 000	1 000	3 000	30 698
3	Non RC	Light	4 000	4 149	700	3 000	1 000	3 000	3 000	4 149	700	3 000	1 000	3 000	30 698
4	1/2 RC	Repro	2 850	3 436	350	1 850	350	1 850	1 850	3 436	350	1 850	350	1 850	20 371
5	1/2 RC	Medium	8 000	13 000	5 000	7 000	5 000	7 000	7 000	13 000	5 000	7 000	5 000	7 000	89 000
6	Non RC	Cationic	4 000	5 571	1 000	3 000	1 000	3 000	3 000	5 571	1 000	3 000	1 000	3 000	34 143
7	RC	Dark	4 000	5 571	1 000	3 000	1 000	3 000	3 000	5 571	1 000	3 000	1 000	3 000	34 143
8	RC	Dark	4 000	5 571	1 000	3 000	1 000	3 000	3 000	5 571	1 000	3 000	1 000	3 000	34 143
9	RC	Special	4 000	5 571	1 500	3 000	1 000	3 000	3 000	5 571	1 500	3 000	1 000	3 000	35 143
10	RC	Black DB	4 000	5 571	2 000	3 000	1 000	3 000	3 000	5 571	2 000	3 000	1 000	3 000	36 143
Total 10 mc			42 850	56 740	13	32 850	13 350	32 850	32 850	56 740	13	32 850	13	32	375
Total 3.33 mc d^{-1}			12 855	17 039	4 189	9 865	4 009	9 865	9 865	17 039	4 189	9 865	4 009	9 865	112

all JD machines is 199 015 L for one batch. JD machines which used to process the light colour consumed less water than a darker colour. JD10 which used to process the black colour consumed 36 143 L of water and it means the highest water consumer comparing to the other JD machines. Comparing with each step, Cooling consumed 56 740 L of water for 10 JD machines.

Figure 3 shows the piping scheme of the initial status of water consumption in the dyeing process of JD machines. All the inlet water for all steps in the dyeing process is supplied only from the water treatment plant (WTP) and also all the outlet water for all steps was carried out to the wastewater treatment plant (WWTP). The total water consumed from WTP and water wasted to WWTP for one day operation for 10 JD machines was about 700 000 L (See Table 1 and Table 2).

3.2 After Implementation

Figure 4 shows the piping scheme of the first action of water consumption in the dyeing process of JD machines. The action is to utilize the cooling water as the input water into the dyeing process. The temperature of the water after used as cooling for the machine can achieve around 85 °C. Utilizing a higher temperature will save both time and energy. By the first action, the total water consumed from WTP and water wasted to WWTP for a one-day operation for 10 JD is about 600 000 L. It saves 14 % of input from WTP.

Figure 5 shows the piping scheme of the second action of water consumption in the dyeing process of JD machines. The action was to utilize the outlet water of OF2 from JD1, JD2, and JD3 as the input water for JD7, JD8, and JD10. Because

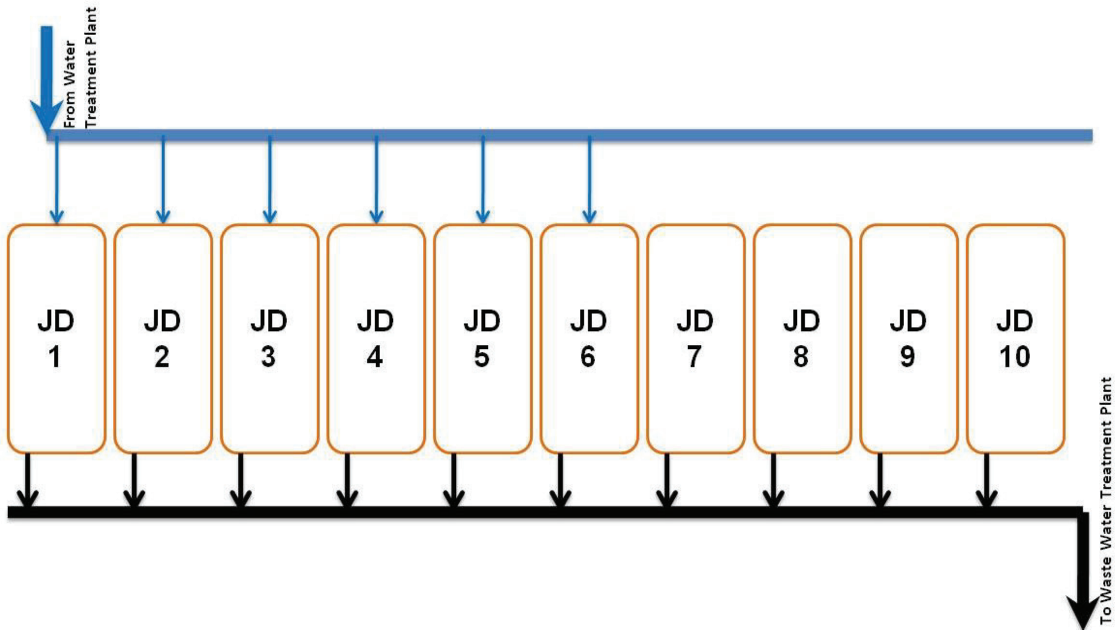

Fig. 3. Piping scheme of the initial status

JD1, JD2, JD3 only process the light colour and the outlet water of its OF2 was tolerated from colour residue and after checking in the Lab Dips. It is safe to use for the dark colour as can be processed by JD7, JD8, and JD10. By the second action, the total water consumed from WTP and water wasted to WWTP for a one-day operation for 10 JD machines was 430 000 L. It saves 39% of input from WTP.

Figure 6 shows the piping scheme of the third action of water consumption in the dyeing process of JD machines. This third action was the next action after the construction of the Hot Water Storage 2 (HWS2) to be finished. There were two works for this third action. The first work was the actions to utilize the outlet water of OF1 from the light colour processed machine, which are JD1, JD2, and JD3 as the input water for JD10 which specialized to process the black colour. The second work was the action to utilize the outlet water of OF2 as the cooling water for JD7, JD8, and JD10. The outlet water of JD7, JD8, and JD10 was stored in HWS2. According to the testing result in Lab Dips, especially for colour stability and colour fastness, there was no significant influence of colour stability and also fastness for the black colour. By the third action, the total water consumed from WTP and WWTP for a one-day operation for 10 JD machines was 400 000 L. It saves 43 % of input from WTP.

The more detailed results from the actions that have been carried out are summarized in Table 3. It clarifies the pipes at the inlet and outlet to the JD machine, as follows; WTP, HWS1, OF2, HWS2, and WWTP. Besides, it also explains the stages of quality inspection at; Lap Dips, Final Quality Control (FQC), JD Quality Control (JDQC). The control system of the inlet and outlet on the JD machines was carried out with a standard program before making changes, as well as with an adjusted program.

Based on the results that have been obtained, there are three important things to discuss. First, understand the process and know where to save. The textile industry, especially for dyeing processing, consumes a lot of water and it also produces a lot of wastewater. The more water consumed will be the more wastewater produce, resulting in a more costly process both freshwater in WTP and wastewater in WWTP. Concerning the issue of environmental problems and also industry competitiveness, CP is one of the effective solutions. With the main process is dyeing itself which water is the main resource, CP can be started from this water demanded process. The most important to start CP in the dyeing process is by understanding the characteristic of colour to be processed in JD machines and also the steps of the dyeing process. Every step of dyeing required water then produces wastewater. After classifying the water required and the water wasted during the dyeing process and

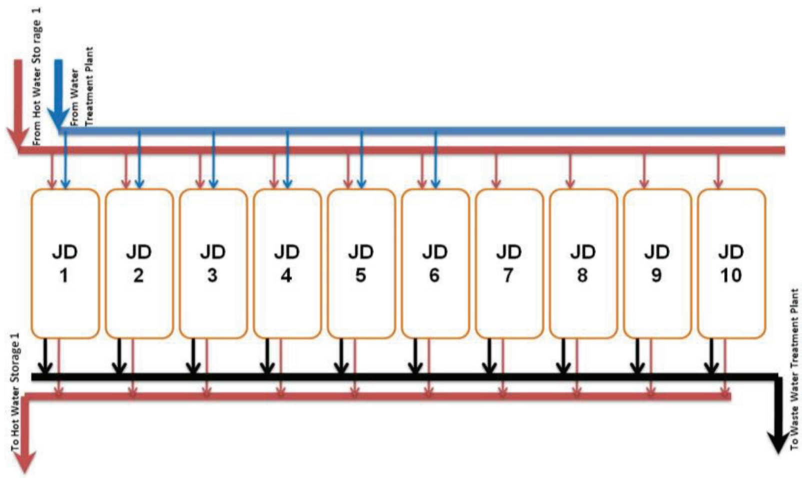

Fig. 4. Piping scheme of the first action

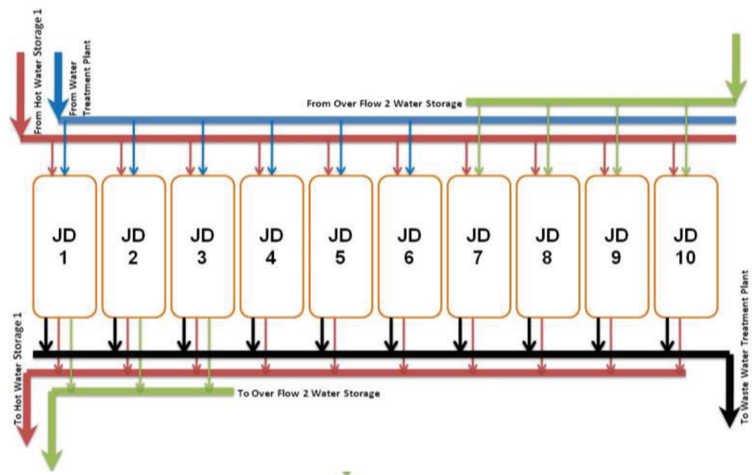

Fig. 5. Piping scheme of the second action

also combined with the characteristic colour to be processed. The next step is to understand how to store and re-use the water from the process.

Second, designing a construction system based on the process flow. This step requires water storage construction and piping installations, which are adapted to the reuse of process wastewater. To work automatically, the reprogramming needs to be done to each JD machine, according to the type of process being carried out. This process must be carried out carefully with high protection to anticipate errors in reusing the process wastewater, which will not affect the quality, productivity, or safety.

Third, monitoring and analyzing the results for further improvement. Reduction of fresh processed in WTP and wastewater processed in WWTP means the reduction of electricity consumed by electrical equipment in WTP, WWTP, and JD machines, and also the reduction of chemical usage in WTP and WWTP. The less water consumption and energy required are the more ecological manufacturing itself. The water consumption in textile wet processing depends on the liquor ratio, as well as on the number of consecutive processes. The machine capacity should also be effectively used to reduce the consumption of process water and chemicals: the dyes are dosed per kg fabric, whereas the auxiliaries are dosed per one process liquor.

The practical application of reducing energy and water consumption that has been carried out in the JD machine can also be carried out in other processes in the DF textile industry, such as washing, de-sizing, or in a process in other industries that also consume the most water and energy. Of course, some things must be adjusted after being analyzed. For the companies, reducing water and energy consumption contribute to reducing production

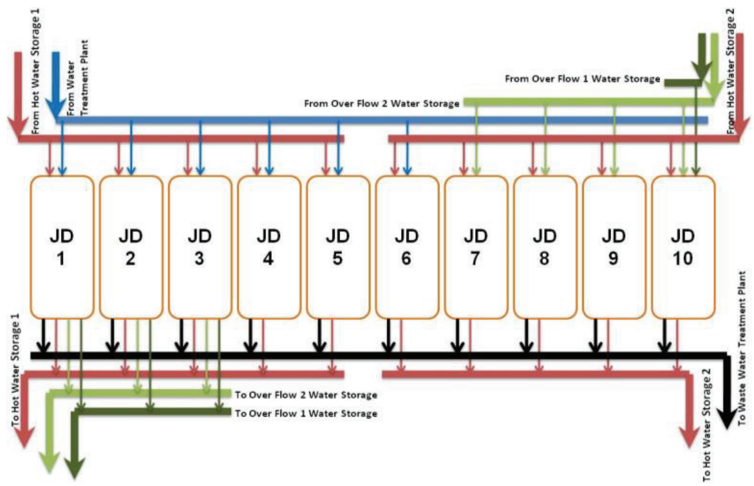

Fig. 6. Piping scheme of the third action

Table 3. Detail summary results of the actions for the dyeing process

Items	Initial Status	1st Action	2nd Action	3rd Action
Water consumption	700 000 L	600 000 L	430 000 L	400 000 L
Consp./JD a day	70 000 L	60 000 L	43 000 L	40 000 L
Input WTP saved	-	14 %	39 %	43 %
Piping: Inlet	WTP	WTP, HWS1	WTP, HWS1, OF2	WTP, HWS1, OF2, HWS2
Piping: Outlet	WWTP	HWS1, WWTP	HWS1, WWTP, OF2	HWS1, WWTP, OF2, HWS2
Quality Control	Lap Dip, FQC	Lap Dip, JDQC, FQC	Lap Dip, JDQC, FQC,	Lap Dip, JDQC, FQC
Automatic Process	Standard Program	Adjust Program	Adjust Program	Adjust Program

costs and their impact on the environment [20], and also strengthening energy security locally [21], which is powered by smart grid technology [22]. For future research direction, the development of smart and precise control mechanisms must be carried out for the appropriate water storage allocation process for a particular process. For cleaner and greener production, the textile industry must involve renewable energy sources in the production process, for example from solar energy using a Photovoltaic (PV) module to generate electricity [23], or a hybrid photovoltaic and thermal (PVT) collector that produces electricity and heat energy [24 - 26]. In addition, the treatment and utilization of other wastes such as exhaust gas [27] also need to be considered in hi-tech [28, 29]. Regarding cleaner and greener production, the textile industry also must be equipped with aerobic and anaerobic water treatment. Furthermore, to increase efficiency, the water treatment should be designed to produce biogas as renewable energy [30].

4. CONCLUSION

Before starting CP, the total water consumed from WTP and water wasted to WWTP for one-day operation for 10 JD was 700 000 L. After the 1st action, by utilizing the outlet cooling water, the total water consumed from WTP and water wasted to WWTP for a one-day operation for 10 JD machines was 600 000 L. In the 2nd action, by utilizing the outlet water of OF2, the total water consumed from WTP and WWTP for a one-day operation for 10 JD machines was 430 000 L. The 3rd action as the next action by utilizing the outlet water of OF1 from the light colour process for processing the black colour and also utilizing the outlet of OF2 for water cooling in the dark colour processing machines, it is predicted that the total water consumed from WTP and WWTP for a one-day operation for 10 JD machines was 400 000 L.

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6. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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