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MATERIAL FLOW ANALYSIS AND ENERGY BALANCE ANALYSIS AS TECHNICAL TOOLS FOR WASTEWATER POLLUTION CONTROL IN TEXTILE AND DYEING INDUSTRY – A CASE STUDY

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Abstract. Quantification of material flows and energy balance in production lines as well as in waste management systems and illustrative presentation of the flows are useful tools for decision making in both cleaner production and pollution control. In this study, using STAN software, the authors have analyzed the material flows, and, using SANKEY software, the authors have analyzed the energy balance of the main production lines and the wastewater management system of a selected textile company in Vietnam. Comparing with “business as usual” scenario, a new scenario with reuse of treated wastewater has been introduced. Loadings of the main pollutants in wastewater as Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Total Phosphorus (T-P) and Total Nitrogen (T-N) were 1419.95, 1736.88, 17.77 and 50.16 ton/year, respectively. One meter of produced fabric consumed 0.025 m^3 of water. The energy consumption rate was 1.695 kWh per m^3 of wastewater treated. Ultrafiltration and ion exchange could enable reuse of wastewater. It could save 1129.05 kWh per day of electricity and 1,804.48 m^3 per day of fresh water to be taken from the river. Ozonation was the most consuming energy process at the wastewater treatment station, accounting for 58.88 % of total wastewater treatment energy consumption.

Keywords: Material Flow Analysis, Energy Balance Analysis, textile and dyeing, STAN, SANKEY.

Classification numbers: 3.3.2, 3.8.2.

1. INTRODUCTION

Vietnam’s textile and garment sector has grown rapidly over the past years, playing a vital role in national socio-economic development [1]. The textile and dyeing industry consume a large amount of water that used mainly in the dyeing and finishing process. Its wastewater is among the most polluting flows from industries, in term of the volume generated as well as the composition [2]. Depending on production features, the textile and dyeing wastewater are characterized by typical parameters such as total suspended solid (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), color, heavy metals, total phosphorus (T-P), total nitrogen (T-N), and salinity [3]. These pollutants can cause serious water pollution problems such as oxygen depletion, inhibition of natural bio-chemical processes, poisoning aquatic life, etc.

The Company X (located in Hai Duong, Viet Nam) has been selected among modern textile and dyeing factories in Viet Nam for a case study. The Company's production capacity was 72 million meters of fabric per year, equipped with latest production and waste treatment technologies [4]. The Company consumed significant amount of water and energy, producing big flow of wastewater, and black listed among most polluting industries who had environmental accidents in the past. Hence, it is important to conduct a study on quantification of material flows and to develop a model of energy consumption which would be essential tools to realize wastewater pollution control and energy efficiency in efficient manners for the Company.

Material Flow Analysis (MFA) is the quantification and assessment of mass flows of matters and substances in a system during a defined period [5]. The principle of MFA is based on the conservation of matters theory. MFA is widely used in environmental engineering, planning and management activities, such as environmental impact assessment, wastewater and sludge management, etc. The value of the flows and stocks of materials within and between the environment and the anthroposphere are results of MFA [5]. However, there were not many studies on MFA for textile and dying industry, particularly in Viet Nam. Furthermore, energy balance tool which could provide necessary information on energy consumption and energy efficiency in different waste management options would be needed for the feasibility choice. Hence, this study was aiming to explore the potential use of MFA tool to quantify pollutants of wastewater treatment process, in combination with Energy Balance Analysis (EBA) for a selected industry which would serve as a basis for selection of feasible improvement options in water - wastewater management and energy efficiency.

2. MATERIALS AND METHODS

The key facilities of the Company included: textile sphere, dyeing sphere, boilers, electricity supply, water supply, drainage, sewerage, pumping station, wastewater treatment plant, emission gas treatment, office area. The Company exploited water from a river nearby for treatment and supply to production lines. Wastewater treatment station should have effluent meeting Vietnamese environment standards QCVN 13:2005/BTNMT and QCVN 40:2011/BTNMT, class A. Main chemicals used in production were dyestuffs, dyeing aids, NaOH, Na_2SO_4, NaClO, H_2O_2, where HCl/H_2SO_4, PAM, PAC were used in water and wastewater treatment [4].

All design parameters of production lines and wastewater treatment systems were collected from Factory's as-built drawings. All operational data were collected from operation logbooks and routine environmental reports of the Company.

To perform the MFA, the Software STofflussANalyse (STAN) developed by the Vienna University of Technology has been selected [5]. To illustrate energy balance of wastewater treatment station, the e!Sankey software has been selected [6]. Two scenarios, "business as usual" as scenario 1, and scenario 2 with treated wastewater reuse have been quantified and analyzed.

The system boundary for MFA included domestic and industrial wastewater flows coming into Factory's wastewater treatment system. The energy consumption was considered and quantified for water treatment, and for wastewater treatment processes. Sludge treatment was included into mass balance and energy calculation, where water bound in sludge was neglected in water balance quantification.

To quantify the material flows, the loading rate, removal efficiency, generated amount of wastewater and sludge, as well as consumed energy of each treatment step were calculated, based on gathered survey database. The weight of each pollutant (ton) was calculated by multiply concentration of pollutant (ton/m^3) to volume of discharged wastewater (m^3). The specific power consumption was calculated using equation Ep = (P × T)/Q where Ep is specific power consumption, kWh/m^3, Q is wastewater flow, m^3/day, P is the rated power of the electrical motor, kilowatt (kW), and T is the working hours in a day, h/day.

3. RESULTS AND DISCUSSION

3.1. The material flow analysis for main pollutants of wastewater

Wastewater from the selected textile and dyeing company included domestic and production flows. Total volume of wastewater generated was about 3,608.96 m^3/day [4]. Based on flow and composition of wastewater generated from each production process, the mass of pollutants in wastewater flows were calculated. Four representing contaminants were selected including COD, total Nitrogen (T-N), total Phosphorus (T-P), and total suspended solids (TSS) [4]. The wastewater treatment flow-chart of Company X is described in Fig. 1. The typical concentration of main pollutants in wastewater of Company X gathered from the survey is shown in Table 1.

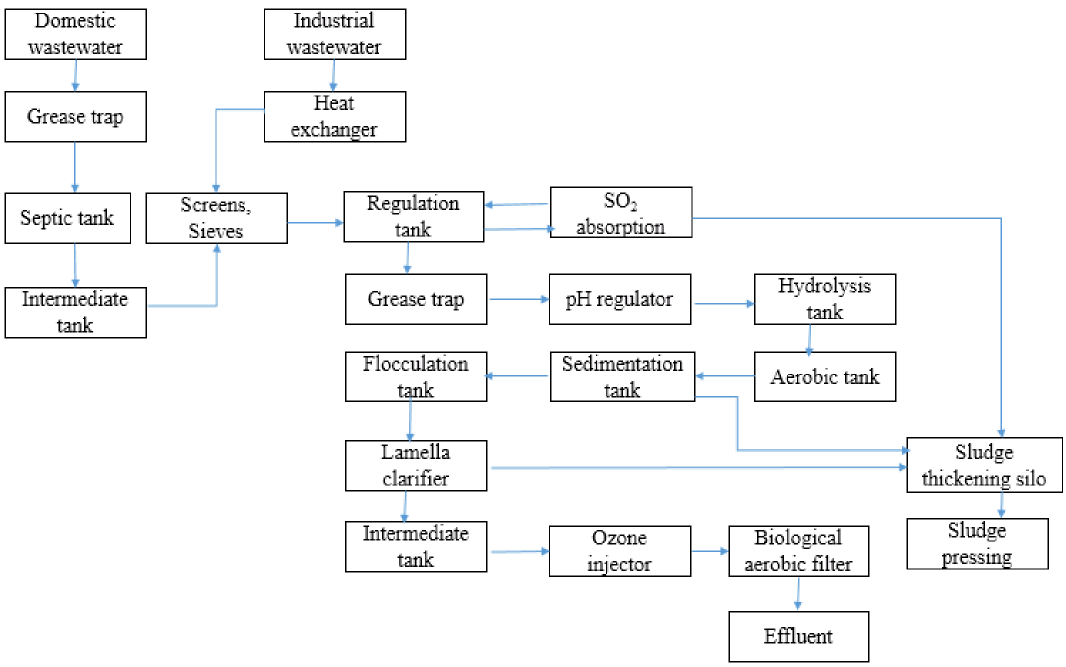

Figure 1. Wastewater treatment flow-chart at Textile and dyeing Company X.

Further, the average removal efficiency of each treatment step was calculated based on gathered survey data, from where concentration and loading of pollutants into next treatment step was calculated. The calculated figures were input for expression in STAN software. Treated wastewater met national effluent standard for the textile industry (QCVN 13-MT: 2015/BTNMT), class A and for common industrial wastewater (QCVN 40:2011/BTNMT), class A [7, 8].

Table 1. Typical composition of raw wastewater of Textile and dyeing Company X [4].

Parameter	Unit	Value	
		Domestic waste water	Production wastewater
TSS	mg/L	331	1343.5
COD	mg/L	700	1087.5
T-P	mg/L	25	13.2
T-N	mg/L	112.5	36.2

3.1.1. Quantification of TSS flow

The total removal efficiency by TSS at wastewater treatment plant was 99.5 %, equal to 1728.23 ton/year of TSS could be removed from wastewater. The average value of TSS in treated wastewater was 4.74 mg/L. The TSS flows at wastewater treatment plant are shown in Fig. 2.

3.1.2. Quantification of T-N flows

The total removal efficiency of T-N was 89.99 %, equal to 45.14 ton/year total nitrogen could be removed from wastewater. The average value of T-N in treated wastewater was about 2.75 mg/L. The T-N flows are shown in Fig. 3.

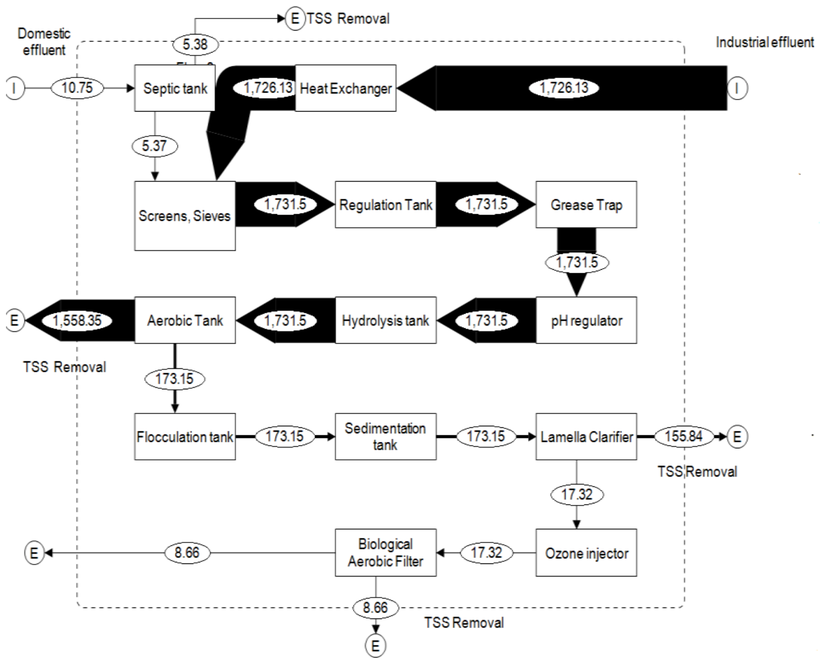

Figure 2. The TSS flows of Company X wastewater illustrated with STAN (units are metric tons per year).

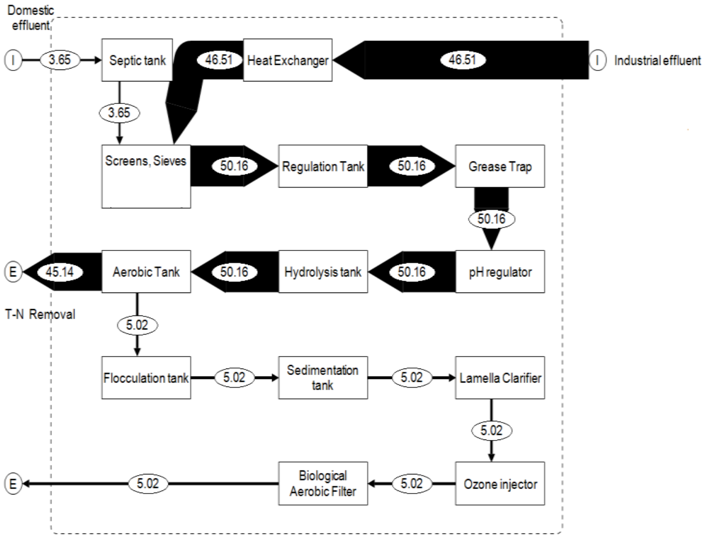

Figure 3. The T-N flows of Company X wastewater illustrated with STAN (units are metric tons per year).

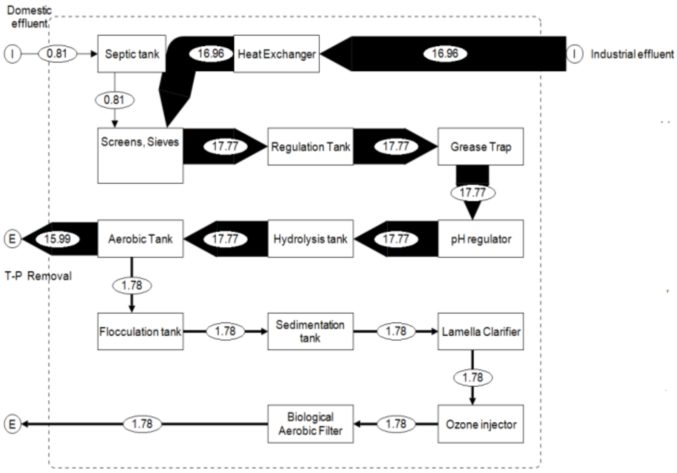

Figure 4. The T-P flows of Company X wastewater illustrated with STAN (units are metric tons per year).

3.1.3. Quantification of T-P flows

T-P removal efficiency was 89.98 %, equal to about 15.99 ton/year total phosphorus could be removed from wastewater. The value of T-P in treated wastewater was about 0.97 mg/L. Fig. 4 illustrates T-P flows at wastewater treatment plant.

3.1.4. Quantification of COD flows

The total COD removal efficiency at treatment plant was 96.54 %, equal to about 1370.80 ton/year COD could be removed from wastewater. The value of COD in treated wastewater was about 26.93 mg/L. Fig. 5 shows COD flows at wastewater treatment plant.

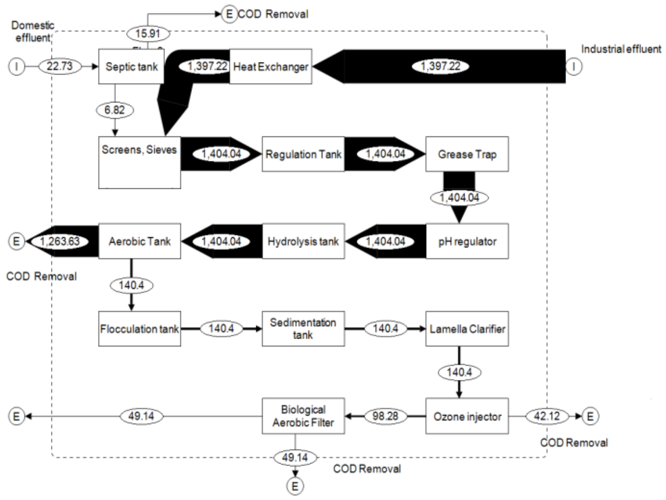

Figure 5. The COD flows of Company X wastewater illustrated with STAN (units are metric tons per year).

3.2. Benefits of reuse of treated wastewater

3.2.1. The water balance in two scenarios

Textile and dyeing industry requires a lot of water for different production processes, and generated a lot of high strength wastewater which should go also through different treatment steps including physical, chemical, and biological before in can be discharged into environment. The more and more stringthened effluent standard and limited receiving capacity of water bodies create pressure on the textile and dyeing factories to improve their cleaner production and water consupmtion, having a wastewater reclamation and reuse vision in a near future [9].

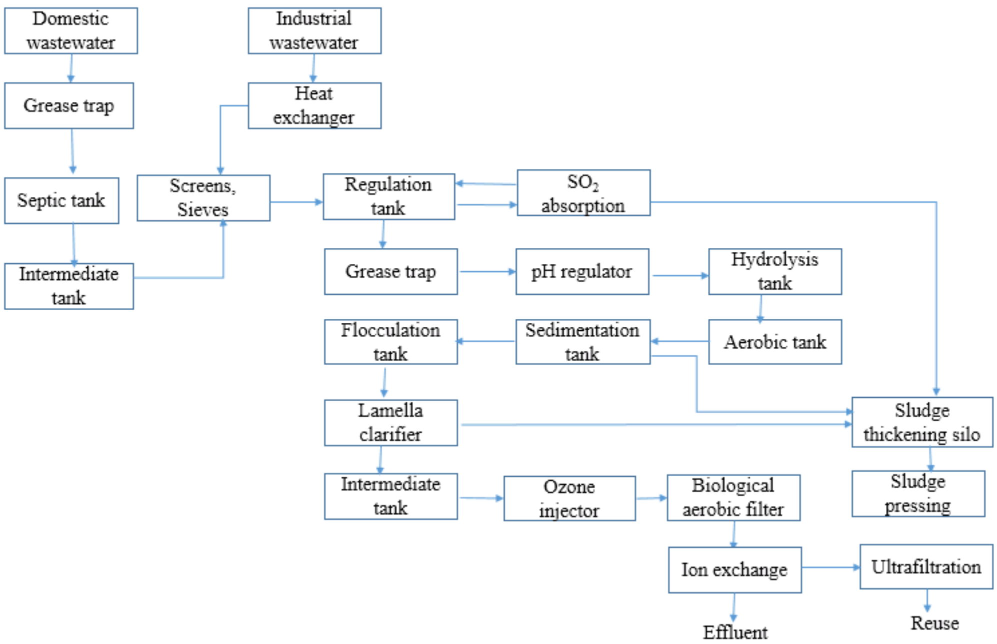

Figure 6. Wastewater treatment flow-chart at Textile and dyeing Company X (scenario 2).

Ultrafiltration and ion exchange are among potentially applicable post-treatment steps to be considered for wastewater reclaimation and reuse and Factory X. However, the new treatment line should be weighted considering benefit-cost effectiveness. For that purpose, comparing existing water usage scheme and new water scheme with wastewater reuse could be very useful. For this, two scenarios of water/wastewater management and energy consumption were developed and analyzed. The first scenario was Factory X with existing single-use of water and wastewater treatment technology. The second scenario was with additional membrane and ion exchange treatment for wastewater reuse for production lines.

The diagram of scenario 2 wastewater treatment scheme is shown in Fig 6. The application of ultrafiltration and ion exchage was considered with assumption 50% of wastewater was reclaimed and reused. This could lead to significant reduction of raw water exploitation, energy for supply treatment, and reduction of amount of wastewater discharged to the environment.

Figure 7 shows the water balance in scenario 1, without reusing wastewater. The average amount of raw water to be supplied to the Factory was 5000 m^3/day.

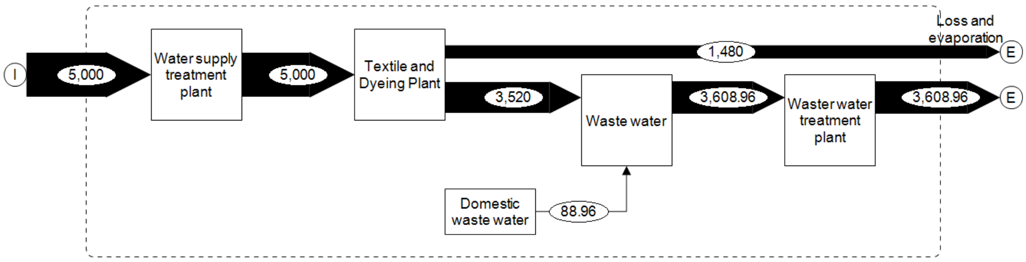

Figure 7. The water balance of Company X in scenario 1 (without wastewater reuse).

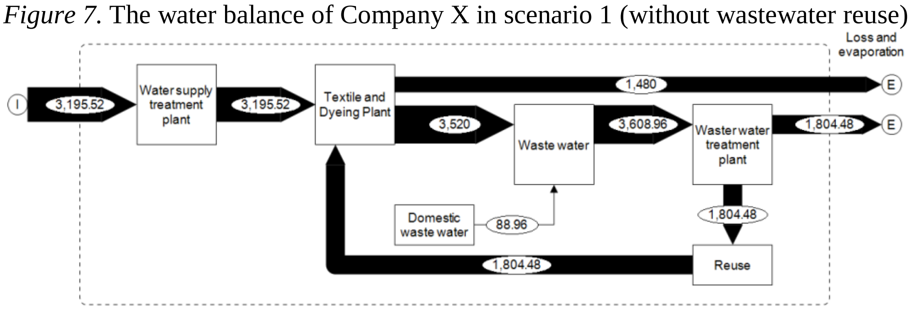

Figure 8. The water balance of Company X in scenario 2 (with wastewater reclamation and reuse).

The water balance in scenario 2, with reuse of wastewater, is shown in Fig. 8, where reuse of wastewater could save 1804.48 m^3/day or 36.09 % of water demand from the source. Besides saving of raw water from the source, the water balance in scenario 2 shows, with reuse of treated wastewater, the amount of wastewater discharged to the environment would reduce 63.91 % which could help to save significant amount of environmental protection fees and reduce environmental risks.

3.2.2. The energy balance in two scenarios

Energy demand for water supply and for wastewater as well as for sludge treatment was quantified. The unit energy demand was calculated based on logged data of daily operation time of individual electrical equipment multiplying to its power or capacity and dividing to amount of water or wastewater treated per day. The e!Sankey software was used for illustration of energy balance diagram of water and wastewater treatment plants in each scenario (Figs. 9, 10, 11). Unit energy consumption rate for each treatment step at water and wastewater treatment is shown, whereas thickness of the arrow is proportional to the value of unit energy consumption rate (kWh/m^3). The diagram shows the advanced oxidation with ozonation was the most energy consuming process at the wastewater treatment plant. Further, the saved energy was mainly from reducing energy required for supply water treatment. If the ratio of reused wastewater increases, the energy saving could increase.

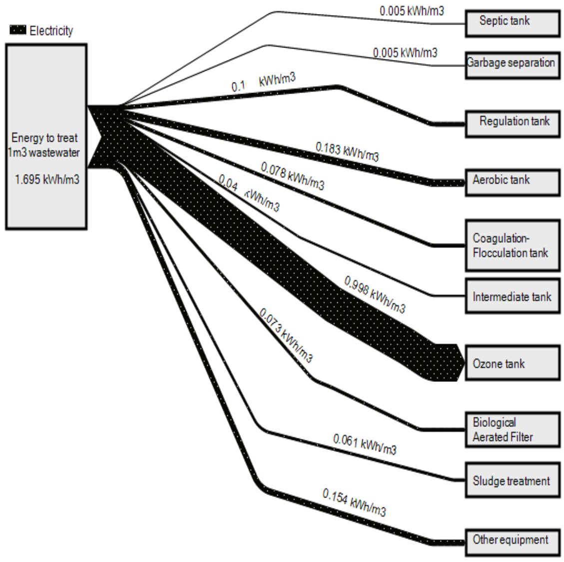

Figure 9. Energy balance at Company X's wastewater treatment plant in scenario 1.

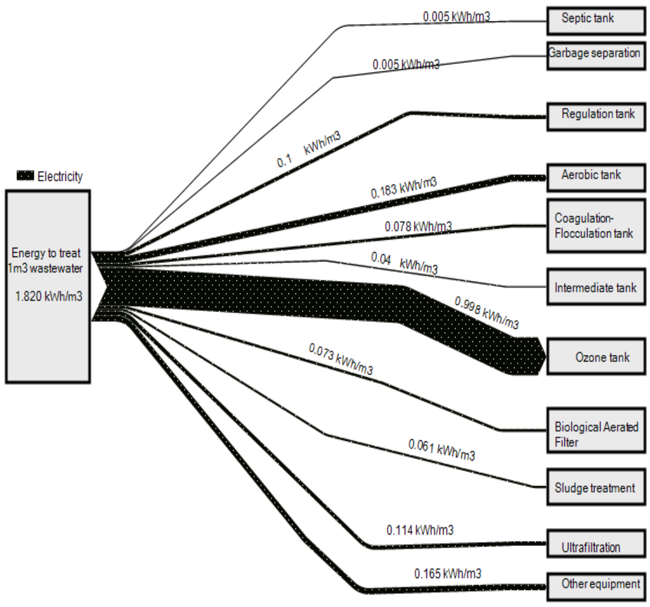

Figure 10. Energy balance at Company X's wastewater treatment plant in scenario 2.

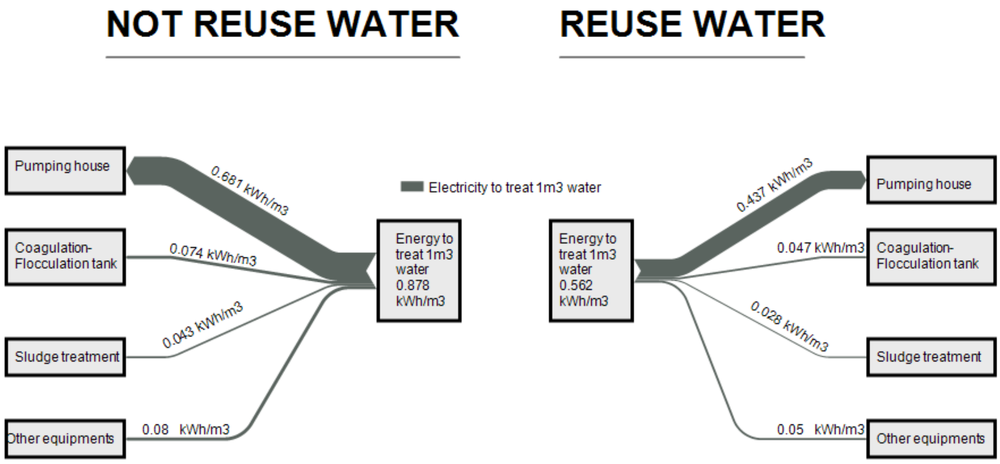

Figure 11. Energy consumption at water treatment plant in scenarios 1, 2.

Additional ion exchange and ultrafiltration processes at wastewater treatment plant in scenario 2 could increase energy consumption for wastewater treatment by 7.40 % compared to scenario 1. Assuming energy consumption rate for each cubic meter of water in water treatment plant was the same in two scenarios, energy consumption of water treatment plant in scenario 2 could decrease by 36.09 % compared to the scenario 1. Total saved energy was about 1129.05 kWh per day. Table 2 shows the energy balance for each scenario.

Table 2. Comparison of energy consumption in two scenarios.

	Unit	Energy consumption	
		Scenario 1	Scenario 2
Wastewater treatment plant	kWh/day	6116.79	6569.55
Water treatment plant	kWh/day	4393.93	2812.11
Total energy consumption	kWh/day	10510.72	9381.67

4. CONCLUSIONS

Quantification of material flows and energy consumptions at Company X textile and dyeing water and wastewater treatment systems have been conducted where STAN and e!Sankey software were used for illustration of the mass and energy flows. The results shown that loadings of the main pollutants in textile and dyeing wastewater as COD, TSS, T-P and T-N were 1419.95, 1736.88, 17.77 and 50.16 ton/year, respectively. After wastewater treatment, the effluent could meet national standards QCVN 13-MT: 2015/BTNMT and QCVN 40:2011/BTNMT. One meter of produced fabric consumed 0.025 m^3 of water. Ozonation was the most energy consuming process at the wastewater treatment station, accounting for 58.88 % of total wastewater treatment energy consumption. Further, the fresh water to be exploited from the source could be reduced by 1804.48 m^3/day or 36.09 % by reusing of treated wastewater after appropriate treatment with additional ultrafiltration and ion exchange processes in scenario 2.

Reclamation and reuse of wastewater could contribute in energy saving of 1129.054 kWh per day. Last, but not least, reuse of treated wastewater could help to reduce volume of wastewater discharge to water body and lower the environmental pollution risk.

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