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Fabrication of textile wastewater treatment block unit using electrochemical method

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ABSTRACT

Textile wastewater, especially when the dyeing section is involved, is remarkably polluted, characterized by a high value of chemical oxygen demand (COD) and color. The process to treat them currently is mostly biochemical and due to the heavy load, the process is remarkably expensive or needs a lot of steps. This research is launched in order to investigate a new alternative electrochemical compact treatment system to treat real textile wastewater with stainless steel, aluminum, and Ti/IrO_2-RuO_2 electrodes. The result showed that after 6 h of treatment at the current density of 6.32 mA/cm^2, aluminum was the best electrode material, capable of removing 99% color, 70% TSS, and 95.2% COD. Ti/IrO_2-RuO_2 electrode was the next, with respective values of 87.6% color, 81.2% TSS, and 79.2% COD removal efficiencies. However, stainless steel failed to have a consistent decreasing trend in pollutant concentrations, netting down at 32.1% color removal, 51.7% TSS removal, and 33% COD removal. The final pH's of the treated waters were 8.304, 6.81, and 5.19, respectively.

Keywords: Textile wastewater; Electrochemical; Stainless steel; Aluminum; Dimensionally stable anode (DSA)

1. Introduction

Textile industry is a vital part in Vietnam economy, being the biggest export earner and employing 2.5 million people in the service. The export turnover in 2017 was over $30 billion USD, marking a 10.23% increase to the year prior [1]. However, with regard to the fabric manufacturing section, most of the material (dyed products) still has to be imported. This is due to several reasons, including the high cost of setting up a dyeing wastewater treatment. The cost incurred is due to the highly polluted nature of the wastewater, which has already contributed to roughly 20% of industrial wastewater worldwide as well as ~70% of harmful contaminants in water. This translates to a small section of companies being set up as dyeing fabric producers, accounting for just 30% of total textile companies [2]. Just like wastewater as a whole, there are three methods of treating textile wastewater (including dyeing section), including physical, chemical, and biological, with each type being further divided. Normally, they are combined together in the same system for maximizing efficiency. Each specific method has its own strength, drawback, and recorded removal ability [3–6]. Recorded researches and studies of textile wastewater treatment include examples such as flotation [2,7], adsorption [8–10], filtration [11,12], oxidative process [13,14], ozonation [15,16], coagulation [15,17], aerobic biodegradation [18–21,25], anaerobic biodegradation [20–24], and anoxic biodegradation [25]. Per practical usage (especially from the visible result of decolorization), the treatment methods are divided into five major groups: physico-chemical, enzymatic, chemical oxidation, microbiological, and electrochemical. The first four methods have certain weaknesses compared to the last one, which is a new method undergoing investigations and researches [6]. The first method, physico-chemical path produces left-overs, which require further treatment before final discharge into the environment. In addition, after

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several runs, some absorbent materials, such as active carbon, silica gel, or alumina, have to be renewed and replace [26]. Furthermore, some physical components such as filtration and membranes also have to be cleaned periodically.

Regarding chemical oxidation solutions, there are some recorded difficulties regarding operations and finance [27,28]. For certain dyeing agents, aromatic rings are present within their molecular structure, this leads to high chemical stability and resistance to attacks of micro-organisms. This means that biological methods are quite ineffective despite having a high degree in simplicity [29]. Regarding enzymatic decomposition, even though this is an effective method [30], the scientifically precise and coherent process is still under study and investigation [31]. In addition, conditions such as temperature and pressure have to be controlled so that enzymes can keep working efficiently. Meanwhile, electrochemical is a new solution being investigated. Compared to the aforementioned methods, electrochemical uses a clean agent, which is an electron. It is concluded that they have good versatility, high-energy efficiency, easy automation process, and a high degree of safety [32]. This leads to highly effective removal of the color [27] and with it, other pollutants criteria such as chemical oxygen demand (COD) or biochemical oxygen demand (BOD). However, electrochemical treatment is only applied at the pilot-scale so far [27,33] due to high energy consumption [33]. This method can be divided further into sub-methods, including electrocoagulation, reduction, oxidation, and electrochemical photo-assisted. The third type can also be further divided into direct and indirect oxidation, while the fourth type can be classified further into Photo-Fenton and photocatalysis [6,33]. In addition to this, a fifth electrochemical method is proposed [33], called "electrodialysis." Electrocoagulation with the aluminum electrode is regarded as a more efficient method than the normal electrochemical treatment [34], where under optimal conditions, 88% BOD_5, 92.6% COD, 96.4% TSS, and 96.5% color can be removed after 90 min with 0.6 A current. Pushpalatha et al. [35] also conduct a research and find out that 56.57% COD can be removed after 105 min, and 93% color with 0.1 M NaCl concentration after 95 min. Another work [36] finds out that 92.97% COD can be removed at 14 V after 80 min of treatment, as well as 96.22% color at 10 V after 20 min. COD can also be removed almost completely with a rate of 97.7% with 50 V voltage after 60 min [37]. However, there is also a report on low removal efficiency, such as 61%–65% for the acidic environment and can get as low as 30% for the basic environment [38]. Electrochemical treatment with stainless steel has also been investigated. Its removal efficiency is recorded at 87.23% COD removal at 14 V after 80 min, and 89.29% color at 12 V after 20 min [36]. Another work [39] reports that at 48 A/m^2 current density and after 180 min, 71% COD and 77% color are removed, the biodegradability of the wastewater also increases. With the Fenton process (iron/stainless steel doped with H_2O_2), up to 57% COD and 83% of color can be removed in the batch method, or 37% and 67.7% in continuous method, respectively [40]. Fenton process can also be used to enhance electrocoagulation [41], where 62.4% COD, 77.3% TSS, and 97.8% color are removed after 120 min treatment. Oxidation application of electrochemistry has also been investigated, however, little is found about its application within the treatment of the textile industry. Farizoglu et al. [47] find out that at current density 1 mA/cm^2 and 5 mM NaCl concentration, 99.67% dye concentration can be removed. Another work [43] combines RuO_2-IrO_2-TiO_2 electrodes with microbiological treatment and notes a 99.96% color removal rate with current density 30 mA/cm^2 and 2 g NaCl per liter after 10 min. The typical reactions in each case have been studied and summarised, for aluminum [44], for dimensionally stable anode (DSA) Ti/IrO_2-RuO_2 [45], and indirect oxidation of steel [46].

This current research will compare the removal efficiency of three-electrode materials, belonging to three respective electrochemical sub-methods, under the same environment and operational parameters. Within this project, electrocoagulation (with aluminum and stainless steel electrode), oxidation (with DSA Ti/RuO_2-TiO_2 electrode, doped by NaCl) are involved. Within the context of treating textile wastewater, all these processes have been tested in the lab-scale prior to this project. The treatment efficiency here is judged with respect to the effluent standard set out by the Vietnamese government for textile wastewater, which is the document "QCVN 13-MT:2015/BTNMT." Among the listed criteria, the five are analyzed, including temperature, pH, COD, color, and total suspended solid (TSS). The final numerical values shall be compared with the standards set out for textile effluent wastewater in the document, including "Standard A" (wastewater discharged into water sources used for household applications) and "Standard B" (wastewater discharged into water sources not used for household applications).

2. Experimental and methods

2.1. Design of the system

The treatment block is designed via SolidWorks, a Computer-Aided Design program. The schematic for the water flow can be seen in Fig. 1. This treatment block comes in three chambers, circulation chamber, electrochemical chamber, and sedimentation chamber respectively from the left. The volumes of the first two chambers are, respectively 60.75 and 31.5 L. Water is moved from the circulation chamber to the second chamber via an adjustable valve, which is set at 250 mL/min. The water will then rise up and flow freely into the last one, there it will be pumped back with the flow rate of 6.67 L/min (or 400 L/h) into the electrochemical chamber. The real dyeing wastewater was collected from Chyang Sheng Ltd. Company, located in Binh Duong province, Vietnam. Due to time constraints, a batch of 20 L of raw wastewater will be treated each time and following diluted to 40% concentration. This is done to ensure easy and smooth treatment operations. The current wastewater treatment system in Chyang Sheng company uses biological and physic-chemical treatment methods in combination. The raw sample of textile dyeing wastewater is then analyzed in the laboratory, yielding the values written in Table 1. Some criteria, such as BOD value or excess chlorine, are not measured due to the lack of proper equipment and time. The requirement for the effluent is calculated and input in the table for comparison's sake.

In this study, three materials are compared against each other: aluminum (grade 1050), stainless steel (grade 304), and Ti/RuO_2-IrO_2 (Samsung Chemical, South Korea). A total count

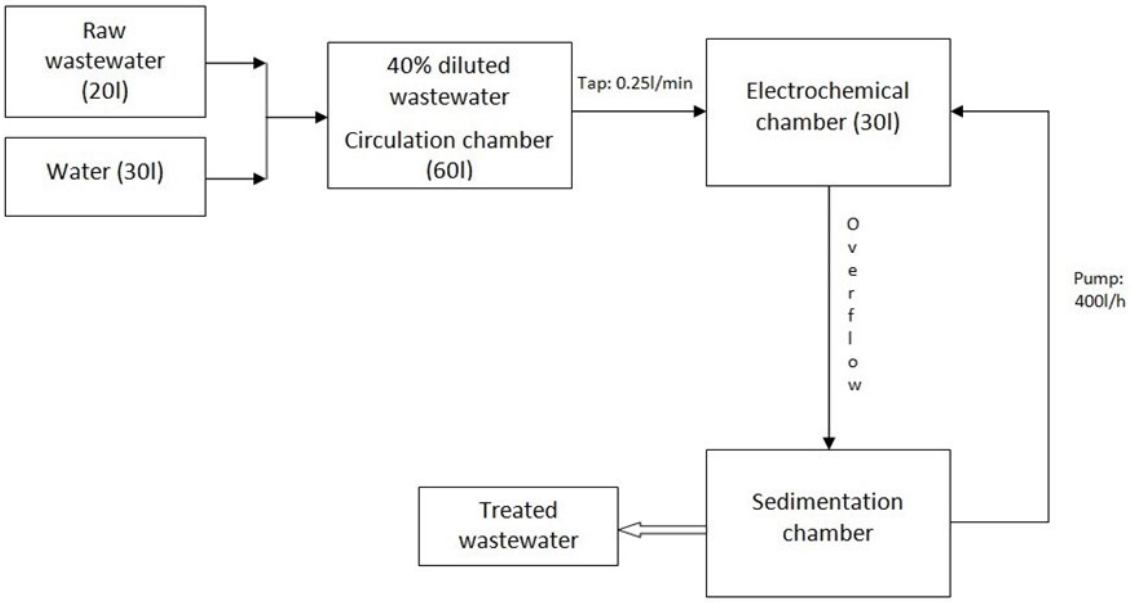

Fig. 1. Water flow schematic in the block unit.

Table 1
Characteristic of sample wastewater

Number	Characteristics	Discharge standard A	Discharge Standard B	Value	Unit
1	pH	10.831	6–9	5.5–9	–
2	Temperature	30.2	40	40	C
3	Conductivity	1,599	–	–	S/cm
4	TDS	1,598	–	–	mg/L
5	Salinity	0.8	–	–	g/L
6	Resitivity	626	–	–	Cm
7	Color	1,800	63.75	170	Pt-Co
8	COD	3,200	85	170	mg/L
9	TSS	2,500	42.5	85	mg/L

of six (06) electrodes is used six times with three anodes and three cathodes in alternating positions, each has an effective area of 100 cm^2. Time-based pollutant removal efficiency will be compared for these three materials, from which the final conclusion will be drawn. The DC power supply (QJ3005XE model, Taiwan), with the output current density of 6.32 mA/cm^2. The treatment block is set up outdoor with a tropical climate, the temperature is ~30°C–32°C with no cloud and rain.

All five concerned criteria are measured with available machinery and laboratory equipments at room temperature. At regular time intervals of 1 h, water is sampled from the sedimentation chamber for analysis. The analysis process will follow the Standard Method for the Examination of Water and Wastewater [47]. pH and temperature will be measured on the same equipment, the handheld Hanna Instrument HI727 model, South Korea. In addition, the final output temperature and pH will be measured. TSS is measured as the difference in the weight of the paper filter before and after the wastewater sample has been poured through (the paper filter will be dried at 103°C before weighing). The dryer used for this job is Memmert UF110Plus, Germany. The value of COD is obtained with Lovibond RD125 COD Reactor (England) and Shimadzu UV-1800 Spectrophotometer (Japan), using the Closed Reflux Colorimetry Method.

2.2. Energy consumption

The power consumption is calculated via the output rating of all electrical components in the system, that is, the power supply and the pumps.

$$EC = E(\text{powersupply}) + E(\text{pump}) = V(\text{out}) \times I(\text{out}) \times t_1 + 2 \times P(\text{pump}) \times t_2 \quad (1)$$

In which:

V (V) and I (A) are the voltage and current output of the power supply.

t_1 is the electrochemical treatment time.

P (pump) is the power rating of the pump, written on its cover.

t_2 is the total operational time of two pumps deployed.

The energy consumption then can be converted into operational cost with information on power prices in Vietnam [48].

For the anodes are being dissolved in an electrolytic environment, their lost content can be calculated with Faraday's laws of electrolysis:

In which

$$m = \frac{(M \times I \times t)}{F \times z} \quad (2)$$

m (g) is the mass of dissolved material.

M (g/mol) is the molar mass of anode material.

I (A) is the current.

t (s) is the time period that the electrochemical treatment takes place.

F is Faraday constant (96,500°C/mol).

z (–) is the number of valence electrons of anode material.

The cost of dissolved material can be calculated as a fraction of the purchase price with respect to the orginal stage.

3. Results and discussion

3.1. Color removal

Fig. 2 shows the color removal efficiency of three electrodes at different electrolysis time. As seen from Fig. 2, the aluminum electrode is highly capable of removing the color from the sample. Within an hour, most of the color has gone and the water is seemingly transparent via naked eyes. From a numerical value, color after electrochemical treatment has been able to reach Discharge standard A. On the other hand, the decrease of color is much slower for the DSA electrode, which might be due to the lack of ammonia within the sample. Nevertheless, within the time frame of 4.8 h, the sample can still reach Discharge Standard B with regard to color. However, the stainless steel electrode is incapable of removing the color. In fact, after the mark of 2 h, more color is generated than being removed. It is theorized that this is due to the release of just-absorbed materials from the anodes back into the wastewater sample.

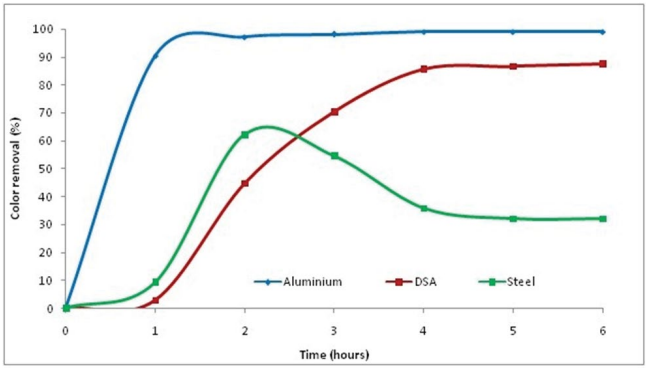

Fig. 2. Color removal efficiency.

3.2. TSS removal

Fig. 3 shows the TSS removal efficiency of three electrodes at different electrolysis time. As seen from Fig. 3, both aluminum and DSA show good ability in removing TSS within wastewater, with aluminum being better in the long run. As the flocculation within the wastewater sample of the aluminum electrode is light and the water column in the sedimentation chamber is low (due to the small sample size), the sludge takes a long time to settle down. It leads to the issue where TSS value can only satisfy Standard B after 5 h mark. Furthermore, during measurements, movements of the containers might also contribute to exciting the sludge, leading to a high value of TSS obtained.

3.3. COD removal

Fig. 4 shows the COD removal efficiency of three electrodes at different electrolysis time. For this section, all values are recorded and measured as the water taken from within the treatment block, that is, diluted and (partially) treated wastewater. As seen from the graph, both aluminum and DSA shows good ability in removing TSS within wastewater, with aluminum being much better at this task. Within the time frame, aluminum electrode can meet the minimum requirement set out by Discharge Standard B. Regarding the stainless steel electrode, just like color removal, it has practically zero effectiveness in removing COD. As mentioned above, the instructor theorizes that this is due to the release of just-absorbed materials from the anodes back into the wastewater sample.

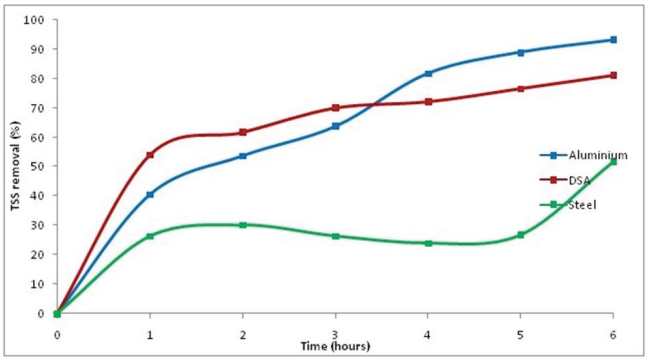

Fig. 3. TSS removal efficiency.

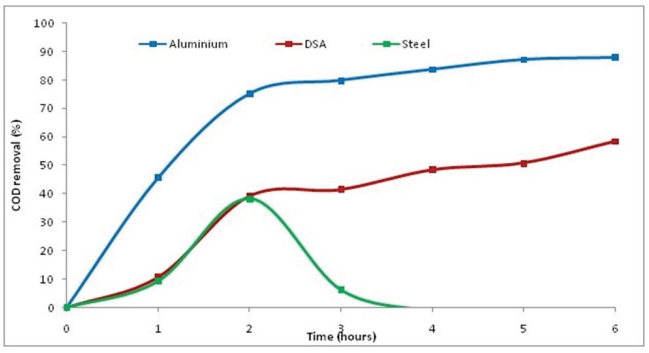

Fig. 4. COD removal efficiency.

Table 2
pH and temperature adjustment

	Initial	Aluminum	DSA	Stainless steel	Allowable range
pH	10.831	8.30	6.81	5.19	5.5–9
Temperature (°C)	55	25	25	25	40

3.4. pH and temperature adjustment

Table 2 shows the pH and temperature adjustment of three electrodes at the output water. As seen above, the pH value of the effluent wastewater has been decreased. Aluminum yields a value larger than 7.0 (neutral) due to the presence of the flocculation $Al(OH)_3$. The OH^- group make the water becoming more basic. Regarding stainless steel, the presence of ion Fe^{3+} increases the concentration of H^+ ions, leading to the acidity of the solution, a pH value smaller than 7.0. For the DSA electrode, while 6.81 is still smaller than 7.0, the difference is small and the discharge wastewater can be regarded as neutral or (very) weak acidity. Regarding cooling power, all three types of materials are capable of limiting the temperature within the final effluent wastewater. It is evident that the heating effect of the current is lower than the natural heat emission of the wastewater into the air, leading to a net decrease in temperature. Overall, leaving the water out in the air is sufficient to cool it down during the treatment process.

3.5. Operation cost

Due to the constraints of the instructors (treating 100 L of raw wastewater each day), the cut off time is 4.8 h, that is, the value for energy consumption stops at this mark, despite the fact that the system is left running for 6 h continuously. In each run, the power supply is running continuously for 6 h with an output of 3.16 A and 12 V, which leads to power consumption of 31.6 W. The two pumps are used, each rated at 6.5 W and due to operational setting, they have a combined total run time of 7 h. Therefore, the total energy consumption (for 4.8 h) is 0.2275 kWh. Applying Faraday's law of electrolysis, the amount of dissolved material can be found, which is 0.00141 g for aluminum and 0.00440 g for steel. These are negligible values, and thus they can be ignored. With the price of water [49] and power [48] it is estimated that with this setting, it would take ~17,600 VND (or $ 0.76 [50]) to fully treat a cubic meter of raw wastewater. This value is slightly higher than the average cost of 15,000 VND (or $ 0.65 [50]) reported by the management board of Chyang Sheng Vietnam Ltd. This value shows comparable value to the available methods, however, practically all the treatment cost of the electrochemical method comes from the power consumption. In addition to upkeep and manpower, the price is expected to increase by a considerable margin. Thus, eventually, electrochemical treatment is not an economically and financially attractive treatment method [51–56].

4. Conclusions

In this research, stainless steel (grade 304), aluminum (grade 1050), and DSA Ti/IrO_2-RuO_2 are used to treat textile wastewater with special regard to the dyeing section. The results show that at the same conditions, aluminum is the best material among all three with regard to all concerned criteria (with practically complete decolorization). However, the current density employed in this research is low and the overall treatment price is still fairly higher, more expensive than the cost involved in existing physic-chemical and microbiological methods in the factory. In addition, the removal ability of stainless steel is different from existing papers on this topic. Therefore, more investigations and researches are required to enhance the removal ability of all materials as well as to find out where the problems are.

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