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Impact of Electrode Materials, Electrode Number, and pH on the Treatment of a Tannery Chrome Effluent by Electrocoagulation

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Abstract

The tanning industry is acknowledged as a significant source of serious industrial pollution on a global scale. Tannery effluent has a wide range and high concentration of contaminants, making it difficult to treat. Chemical coagulation has been utilized for many years to get rid of soluble metal species and colloidal suspensions from tannery wastewater. Electrocoagulation is an emerging technology that does the same task at a lower cost. This research has been undertaken to determine the most effective electrode material for electrocoagulation. Firstly, tannery chrome effluent was collected from Savar Tannery Estate, and the wastewater was characterized by three parameters. The parameters were pH, color, and Cr. The electrodes used were made of stainless steel, mild steel, and aluminum. The number of electrodes was also varied to check the effect of the number of electrodes on the treatment process. The tannery chrome effluent was treated in six batches, each time using a different electrode configuration. Electrocoagulation was conducted for 90 minutes for each batch, followed by 30 minutes of settling time. Each of the treated wastewaters was again analyzed for parameters. Stainless steel electrode has been found to be the most effective for chromium removal (99.6%). However, regarding overall pollutant removal, mild steel worked the best among the three electrodes (i.e., color and chromium removals were 97.9% and 99.2%, respectively). The higher value of correlation coefficients indicates that there is a strong dependency among color removal, chromium removal, and pH value.

Keywords: *Electrocoagulation; tannery wastewater; electrodes; wastewater treatment; removal efficiency.*

1 Introduction

The tanning industry is one of the oldest manufacturing sectors in Bangladesh. It belongs to one of the most polluting industrial sectors. The processes of leather tanning are completely wet processes, in need of enough water which turn almost 90% of the used water into wastewater. Today, there is significant concern over this industrial pollution. Due to its ease of use, an electrochemical method termed electrocoagulation has recently gained a lot of attention for treating tannery waste. Due to the oxidation and reduction events that occur throughout this procedure, no additional chemicals are needed. As a result, the system's operation and maintenance are easy. Low power usage is also anticipated. Compared to conventional flocculation-coagulation, electrocoagulation has the benefit of eliminating the smallest colloidal particles because charged particles have a higher propensity to become coagulated and destabilized due to the electric field that propels them into motion.

Electrocoagulation as a treatment process of tannery wastewater has been being used in many countries of the world. In Bangladesh, chemical coagulation is used mainly as a treatment method. This results in higher treatment costs which is responsible for the disinterest of industries in the whole treatment process. As electrocoagulation is cheaper than chemical coagulation, this method should be employed hugely in the tannery industries of Bangladesh. But, in reality this method is not widespread in Bangladesh. Rigorous research has been done in China on electrocoagulation. But in Bangladesh, very few research has been done on the topic. No other research from Bangladesh had been found that encompasses our question that led to our topic of research. The question is, “Which electrode material is best for treatment of tannery chrome effluent?" This research work would help to treat tannery chrome effluent more efficiently before mixing it with the combined tannery wastewater.

The objectives of this study are to characterize the tannery chrome effluent, to observe the effectiveness of electrocoagulation for removing pollutants from tannery wastewater, to compare the performance of different electrode materials for electrocoagulation, to observe of the effect of number of electrodes in each treatment process, and to find out the tentative correlations among pH, color removal and chromium removal.

Treatment performance of an EC cell depends on various factors including wastewater characteristics, current density, pH, conductivity, electrodes (materials, numbers, size, spacing), electrode connection mode, operating time, bubble density, etc. (Emamjomeh and Sivakumar, 2009; Sengil and Ozacar, 2009). Electrode material has a great impact on treatment performance as it determines the pollutants removal mechanism (Nasrullah et al., 2018). Al and Fe are the most commonly used electrodes and are inexpensive and easily available (Kobya et al., 2006; Zaied and Bellakhal, 2009). Besides, some other materials such as Pt, TiO_2, SnO_2, PbO_2, graphite, and boron-doped diamond (BDD) electrodes have also been employed for different EC applications (Islam, 2019; Top et al., 2011). The relative performance of different electrode materials depends on the target pollutant to be removed (Kabdasli et al., 2012; Zaied et al., 2020). Electrodes may be connected to the power source either in monopolar (MP) or bipolar (BP) connection mode (Kobya et al., 2007; Sahu et al., 2014). In the MP arrangement, electrodes can be connected either in parallel (MP-P) or series (MP-S) arrangement (Kobya et al., 2007; Modirshahla et al., 2008). Electrode connection has a dual function on treatment efficiency and energy consumption, and appropriate connection mode is selected based on applications. Several researchers observed BP connection having higher treatment efficiency while MP connection to be more cost-effective for both organic and inorganic pollutants (Golder et al., 2007; Vasudevan et al., 2013). Studying various EC applications, MP-P arrangement can be proposed for optimum performance in most applications.

2 Methodology

The whole field work may be broadly classified into 4 categories: (1) collection of wastewater, (2) experimental set-ups carried out for research work, (3) bench-scale experiments, and (4) measurement of parameters. Six sets of treatment processes were carried out by electrocoagulation to determine the impact of the electrode material and number of electrodes on the treatment efficiency. For our research work, we collect chrome water rather than normal sewage water from Apex Tannery Ltd., Bangladesh. About 50 liters of wastewater are collected in two Jumbo Jars each with a capacity of 25 liters.

All the treatments were done in a cubic-shaped container. The length, width, and height of the container were 295 mm, 115 mm, and 130 mm, respectively, with a capacity to hold 4.5 liters of sample. The container was made of organic glass. The electrode materials used for the treatments were Mild Steel, Stainless Steel, and Aluminum. The dimensions of the electrodes were 15 cm in length and 9 cm in width. There was a 1.5 cm flange in each electrode that was at a right angle to the main plate, in which two holes were inscribed at 7 cm center-to-center spacing. The diameter of the holes was 0.5 cm. A wooden platform was required to hold the electrodes together. Since wood is non-conductive, it facilitates the EC process. The length, width, and thickness of the wooden platform were 40 cm, 10 cm, and 1 cm respectively. There were two rows of holes 7 cm apart. Each row had 10 holes at 20 mm center-to-center spacing. A DC power supply was used as a power source.

At first, the glass container was placed on a large experiment desk with a plain surface. Then the electrodes were attached to the wooden platform with the help of nut-bolts. All the nuts were tightened properly by means of pliers. It was ensured cautiously that no electrode touched the adjacent electrode somehow. Then the wooden platform with electrodes was placed over the glass container so that the group of electrodes remained in the middle of the container. The gap between the two adjacent electrodes is 2 cm, and the electrodes were placed in the container in such a way that they were about 3 cm above the bottom of the container. Then the electrodes were connected with positive and negative wires in an alternating manner (MP-P arrangement), which means two adjacent electrodes were connected with oppositely charged terminals. The two other ends of the positive and negative wires were connected to the DC power source. The main plug of the DC power source was connected with the original AC power supply.

3 Experimental Procedures

Before starting the treatment process, the different water quality parameters were found out for the raw wastewater. Since we had to run six treatments with different electrode combinations, the same procedure was repeated six times sequentially. The six electrode set-ups are as followed-

I. Stainless Steel (4 Cathodes and 3 Anodes)

II. Stainless Steel (3 Cathodes and 2 Anodes)
III. Mild Steel (4 Cathodes and 3 Anodes)
IV. Mild Steel (3 Cathodes and 2 Anodes)
V. Aluminum (4 Cathodes and 3 Anodes)
VI. Aluminum (3 Cathodes and 2 Anodes)

The raw water kept in the Jumbo Jar was mixed properly by random shaking. Then the water was poured into the container up to 120 mm height. Then the switch of the AC power line was turned on and the switch of the DC power source was also turned on immediately as well. Current flow was set at 5 A by rotating the left knob. Timer was started in stopwatch after the turning on of the power supply switch. The water in the container was mixed up in a regular interval through stirrer to facilitate floc formation. During the stirring process, the current flow was kept off temporarily. The treatment process was carried out for 90 minutes. After that, the switch of the power supply was turned off and the timer was stopped as well. Then the set-up was kept at rest for 30 minutes to facilitate sedimentation. Since, flocs were settled at the bottom of the container and foams were accumulated at top of the water surface, around 200 mL treated water was extracted from the middle clear layer through the pipette after sedimentation. 100 mL for Chromium test; and remaining 100 mL for other parameter tests. The above process was repeated separately for 6 different electrode combinations. In this research work, three water quality parameters were mainly tested. Those were: Chromium, Color, and pH.

4 Results and Discussions

At first raw chrome effluent was tested to characterize the wastewater. The parameters tested were Color, Chromium, and pH. The same parameters were tested each time the treatment was done. The amount of residual pollutants were found out through these tests.

Table 1. Comparison of some parameters of chrome effluent before and after treatment using various electrode configurations

Water Quality Parameter	Unit	Raw Wastewater	Stainless Steel		Mild Steel		Aluminum	
			7 Electrodes	5 Electrodes	7 Electrodes	5 Electrodes	7 Electrodes	5 Electrodes
pH		3.58	7.67	9.87	10.66	9.93	4.08	3.85
Color	Pt-Co	1045	56	32	30	14	77	91
Cr	mg/L	759.7	5.4	0.9	8.5	3.7	50.1	67.4

4.1 Color Removal

Color had been significantly removed using all electrodes but with slightly varying results (Fig. 1). Mild Steel electrodes had been the most effective for color removal. The highest removal of 98.7% was found in the study. Aluminum electrodes perform relatively poorly in terms of color removal. For SS and MS, five electrodes performed better than seven electrodes, but aluminum demonstrated the opposite.

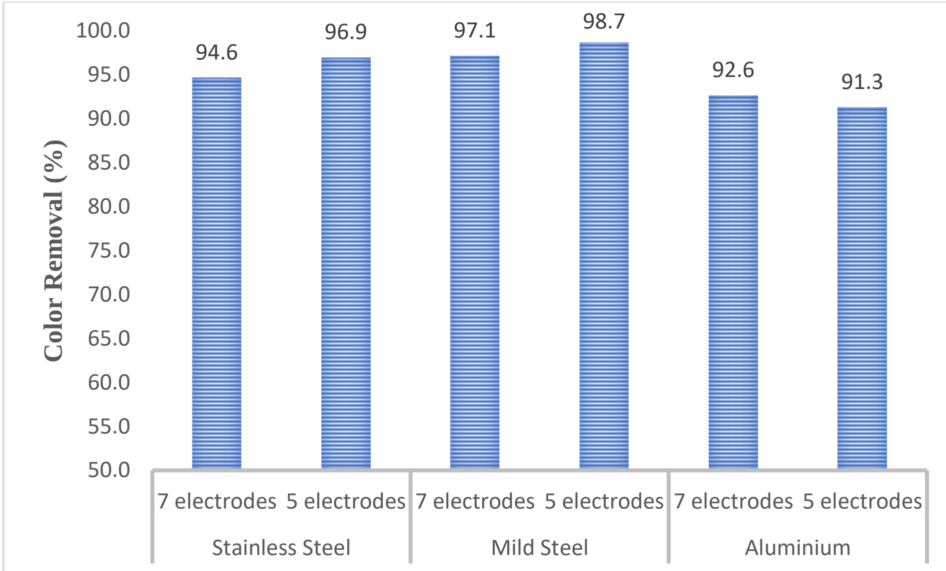

Figure 1. Removal Percentage of Color by treatment using various electrodes

4.2 Chromium (Cr) Removal

Chromium had been significantly removed from all electrode configurations. The best electrodes for removing Cr had been those made of stainless steel (Fig. 2). 99.9% Cr removal was achieved using five stainless steel electrodes. Regarding Cr removal, Aluminum electrodes perform relatively poorly. The reason for this subpar performance while employing aluminum electrodes is that there was no pH increase. For SS and MS, five electrodes outperformed seven electrodes similarly to color removal, but aluminum showed the opposite.

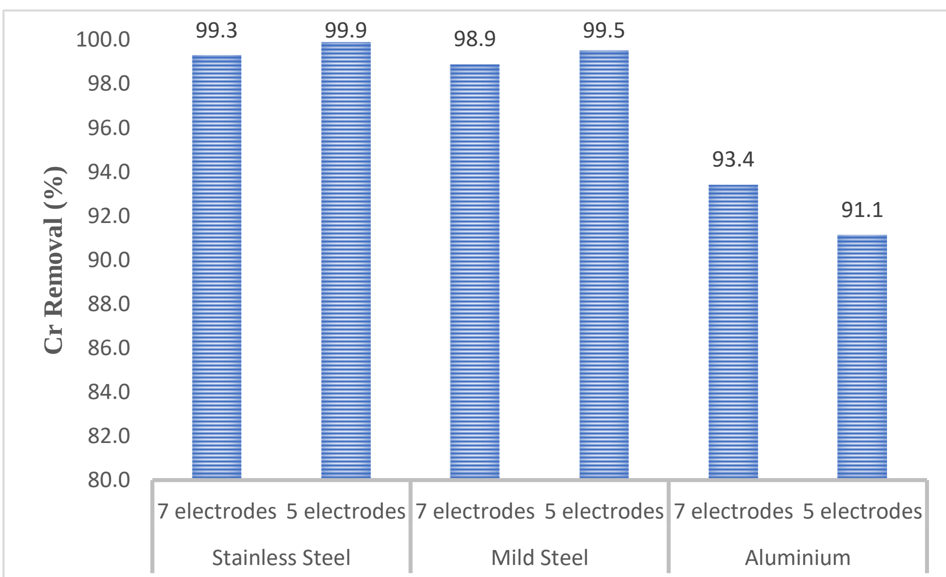

Figure 2. Removal Percentage of Chromium by treatment using various electrodes

4.3 Correlation Between pH and Chromium Removal

Heavy metals like Cr are highly soluble in low pH, i.e., acidic environments. As pH increases, an alkaline environment is introduced, and Cr coagulates easily (Figure 3). The value of the correlation coefficient is 0.855, which shows the high dependency of Cr removal on pH.

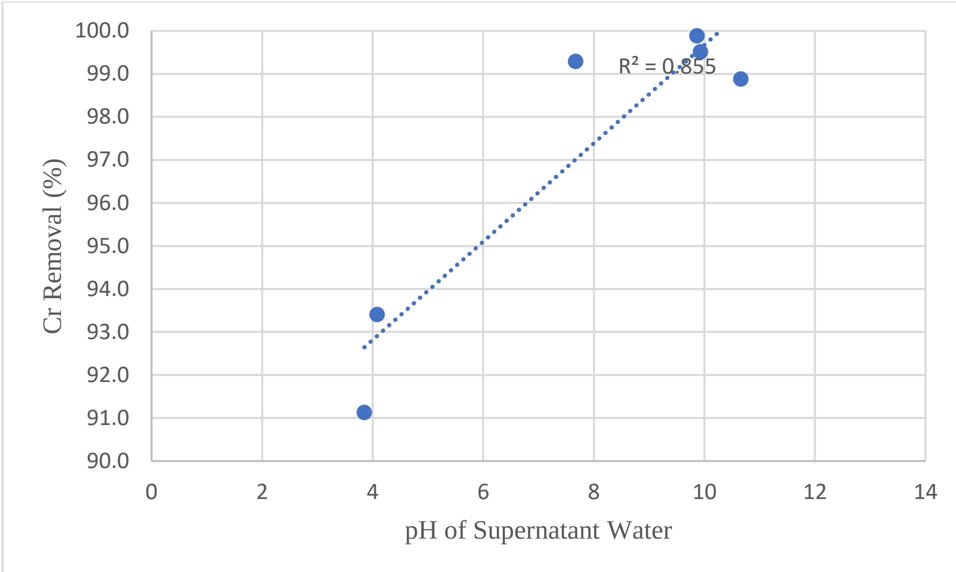

Figure 3. Chromium removal (%) vs pH in different electrocoagulation setups

4.4 Correlation Between pH and Color Removal

The color of tannery effluent is due to the presence of organic matter and heavy metals like chromium. In tannery chrome effluent, chromium is the predominant source of color. Heavy metals are removed with an increase in pH. As the principal source of color is removed with an increase in pH, the color removal percentage is also high (Figure 4). The value of the correlation coefficient is 0.91, which shows the high dependency of pH on color removal.

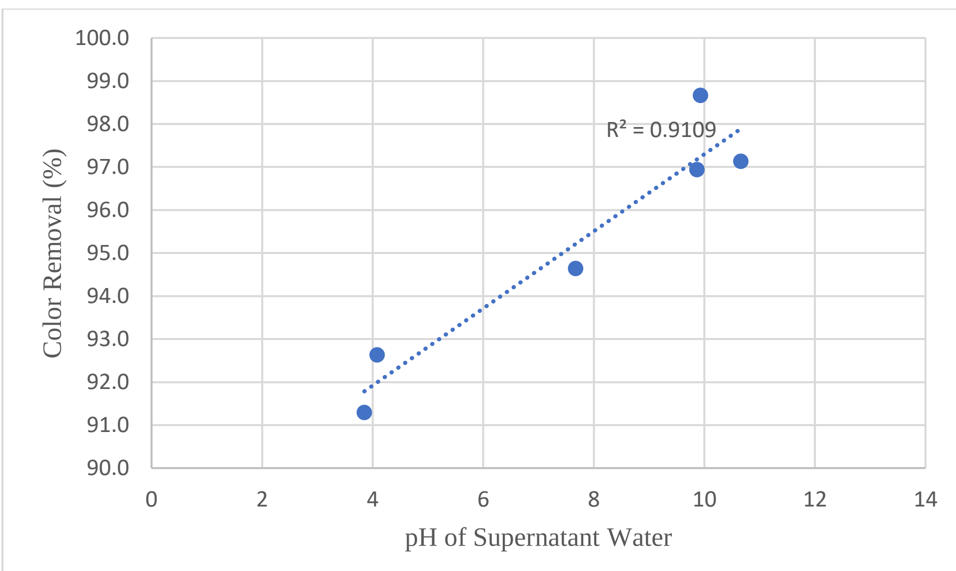

Figure 4. Color removal (%) vs pH in different electrocoagulation setups

5 Conclusion

The major goals of this research work were to examine the electrocoagulation performance of various electrode materials and the impact of the number of electrodes used in each treatment procedure. Besides, correlations among pH, color removal, and chromium removal are also examined. Based on all the findings and discussions of the study, it is observed that tannery chrome effluent was found to be substantially different from tannery combined effluent in terms of pH, although color and chromium concentration values were almost similar to tannery combined effluent. Electrocoagulation is highly effective in removing color and chromium from the tannery wastewater. In terms of removing chromium, the stainless-steel electrode outperforms the other electrode materials (99.99%). Mild steel electrode is better than the other electrode materials used in terms of color removal (98.7%). Usually, electrode number five performs better than electrode number seven. Although the performance of stainless steel electrode is very close to that of mild steel electrode, mild steel is the most successful electrode material in terms of the parameters investigated in the study because it significantly removes both the pollutants we considered (removals of color and chromium were 97.9% and 99.2%, respectively). The significant value of the correlation coefficients confirms that the removal efficiency of color and chromium is highly dependent on pH value (R^2 = 0.911 and 0.855, respectively). Both of the parameters show a strong proportionality with the pH value.

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