Efficient Removal of Heavy Metals from Electroplating Wastewater using Electrocoagulation

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Abstract- Heavy metals are toxic to humans on consumption if disposed with inefficient treatment facilities in water bodies or on land. Such industrial wastewater needs effective treatment before disposal as they may mostly contain heavy metals in dissolved form, advance treatments are required for efficient, economical with low operational and maintenance systems for commercial utilisation. Electro-coagulation was experimented with electroplating wastewater using Fe and Al electrode as material at pH variation of 3.0, 5.0, 7.0 and 9.0 for 30 minutes of retention time. The influence of electrode material, pH and retention time was explored during experimentation also corresponding with electrode and energy consumption. Maximum removal efficiency on optimization was observed during pH 9.0 at 0.1 A current using electrode combination of Fe-Fe and Fe-Al 100.0% of nickel and chromium removal within 20 minutes at cost of INR 90.0/m^3 compared to Al-Al and Al-Fe removal efficiency and consumption cost

Index Terms- electrocoagulation, removal efficiency, operating parameters.

I. INTRODUCTION

Heavy metals in effluent are serious problem of concern during treatment process to be efficient. Electroplating wastewater contains heavy metals such as nickel, chromium, zinc and iron after discharged from treatment unit. These heavy metals above limits can cause adverse effect on the humans and environment. Chromium is carcinogenic [1]. Nickel can cause decreases in body weight, heart liver damage, dermatitis and suspected to cause cancer [2, 3]. Zinc above 5mg/l [4] gives astringent taste and opalescence in water, also health problems such as stomach cramps, skin irritations, vomiting, nausea and anaemia, while chronic exposure could lead to copper deficiency in man. [5, 6]. Iron above 0.3 mg/l can affect appearance affecting domestic water supplies, promotes iron bacteria, and staining of laundry cloths [4]. The ingestion of large quantities of iron salts may lead to severe necrotising gastritis with vomiting, haemorrhage and diarrhoea followed by circulatory shock, also diseases of aging such as Alzeihermer's disease, other neurodegenerative disease, arteriosclerosis, diabetes mellitus may all be contributed to by excess iron and copper [6]. Hence heavy metal treatment is important before disposal of effluent on land or in water bodies, with possibility of metals getting dissolved or formation of complex. Various treatments are employed to treat wastewater containing small or large concentration of heavy metals. Methods such as adsorptions [7], bio-sorption [8], ion exchange [9], zeolite [10], phytoremediation [11], nanomaterial [12] and chemical coagulation [13] are used for the efficient removal of heavy metals, still these methods have their own barriers during treatment. Electrocoagulation is considered as the effective treatment technique over methods listed above. The merits of the treatment which are considered over other techniques are less sludge generation, no chemicals used, less retention time, no problem on selectivity of contaminants and easy in operation, only disadvantage is changing sacrificial electrodes of the system [14,15,16,17,18] . Electrocoagulation has shown effective results on textile wastewater [14], pulp and paper wastewater [15], tannery wastewater [16], slaughterhouse wastewater [17], and dairy wastewater [18]. The aim of this study was to investigate electrocoagulation process efficiency to remove heavy metals using iron and aluminum electrodes determining pH and optimal current.

II. MATERIALS AND METHODS

A Characterization of wastewater:

The electroplating wastewater used in this study was collected within the Kolhapur city vicinity. The wastewater was characterized for pH, conductivity, and heavy metals present according to Table 1.

Table1: Characteristics of metal plating wastewater

Characteristics	Units	Values
pH	-	3.0
Conductivity	mS/cm	52
Nickel	mg/l	25
Chromium	mg/l	1.8
Zinc	mg/l	1.2
Iron	mg/l	0.25

B Electrocoagulation procedure:

The present study was performed in laboratory on collected samples of electroplating wastewater industry. Characteristics of wastewater are illustrated in Table-1. Fig-1 shows the set-up of electrocoagulation bench model at laboratory. Set-up includes DC power supply, iron and aluminum electrodes (150 mm height × 30 mm width × 3mm thickness), spacing of 10 mm between

electrodes, glass jar (500 ml capacity), electrode connection (monopolar arrangement) and stirring speed 200 rpm. Wastewater parameters like pH, conductivity were determined and heavy metal concentrations were analyses using atomic absorption spectrophotometer (AAS). Parameters of the sample was analysis at pH 3, 5, 7and 9 at current 0.5A, 1.0A and 1.5A for the duration of 10, 20 and 30 minutes using Iron and aluminum electrodes. pH of the sample was adjusted using sulphuric acid and normal sodium hydroxide. An aliquot of 10 ml from the middle of the EC cell was collected using pipette and filtered to remove flocs. Finally sample was analysis for heavy metal concentration for pH, electrode combination and reaction time.

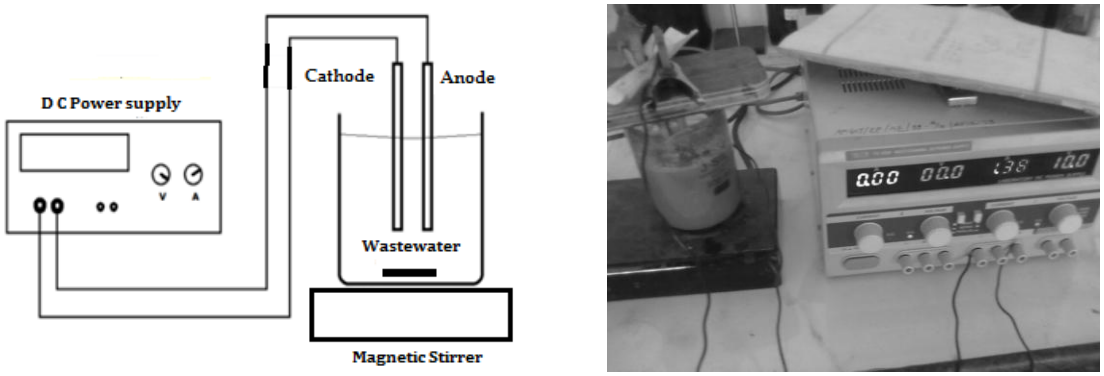


Fig-1: Bench-scale EC reactor with monopolar electrodes

C Calculation:

Energy Consumption

$$E = \frac{U \times I \times t}{V} \quad \text{..... eq-1}$$

Where E- is the energy consumption (kWh/m^3), U - is the applied voltage (V), I - is the current intensity (Amperes), t - is the electrocoagulation time (hr.), and V - is the volume of the treated wastewater (m^3).

Electrode consumption:

$$W = \frac{I \times t \times Mu}{Z \times F \times V} \quad \text{..... eq-2}$$

Where, I- is the current (Amperes), t- is the operation time (hr.), M_w - is molecular weight of the substance (g/mol), F- is Faraday's constant (96500 C/mol), Z- is the number of electrons involved in the reaction at anode (2 for Fe^{2+} and 3 for Fe^{3+} and Al^{3+}), V- volume of wastewater (m^3) and W- is the quantity of metal dissolved (gm) during electrochemical reaction.

Efficiency of Treatment:

$$n\,\% = \frac{C - Cx}{C} \times 100 \quad \text{..... eq-3}$$

C- Initial concentration of sample used for experiment; Cx – concentration in sample at time after treatment.

Figure 2: Graph for Nickel removal efficiency at varying current and time using different electrode combinations.

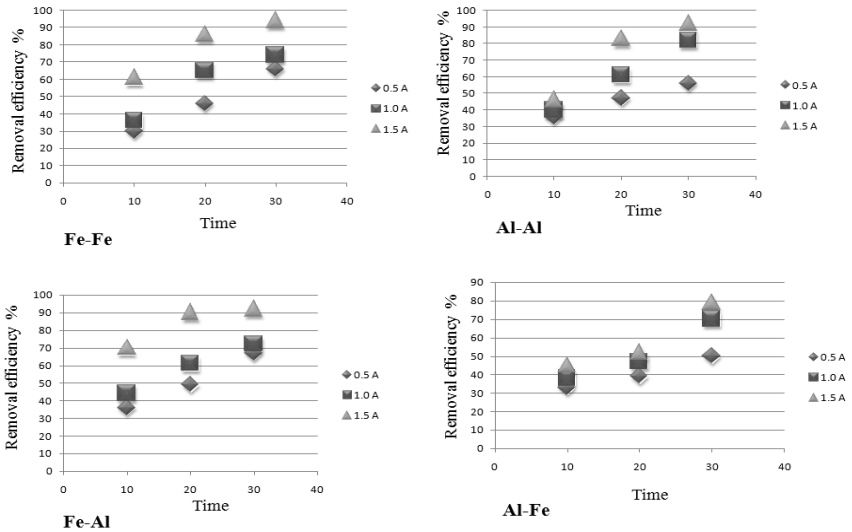


Figure 3: Graph for Chromium removal efficiency at varying current and time using different electrode combinations.

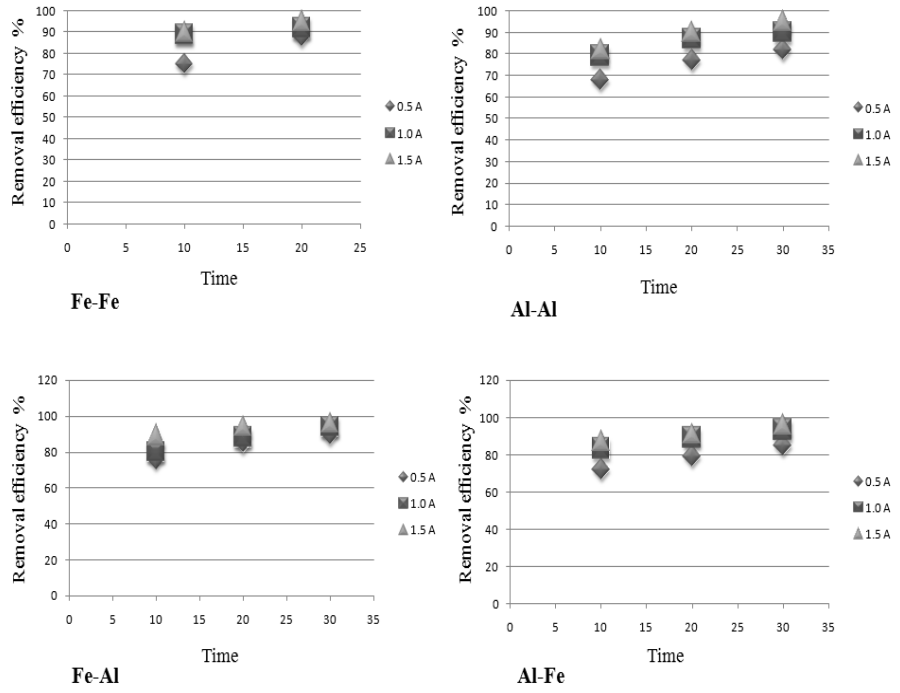


Figure 4: Graph for Chromium removal effeciency for optimized current 1.0A at varying electrode combination and pH values.

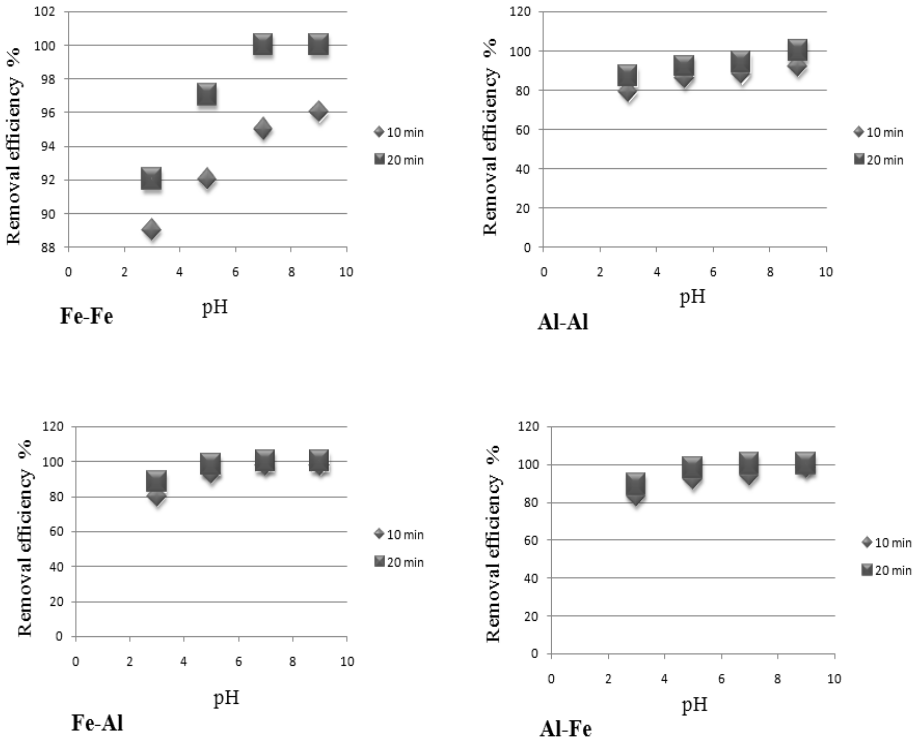
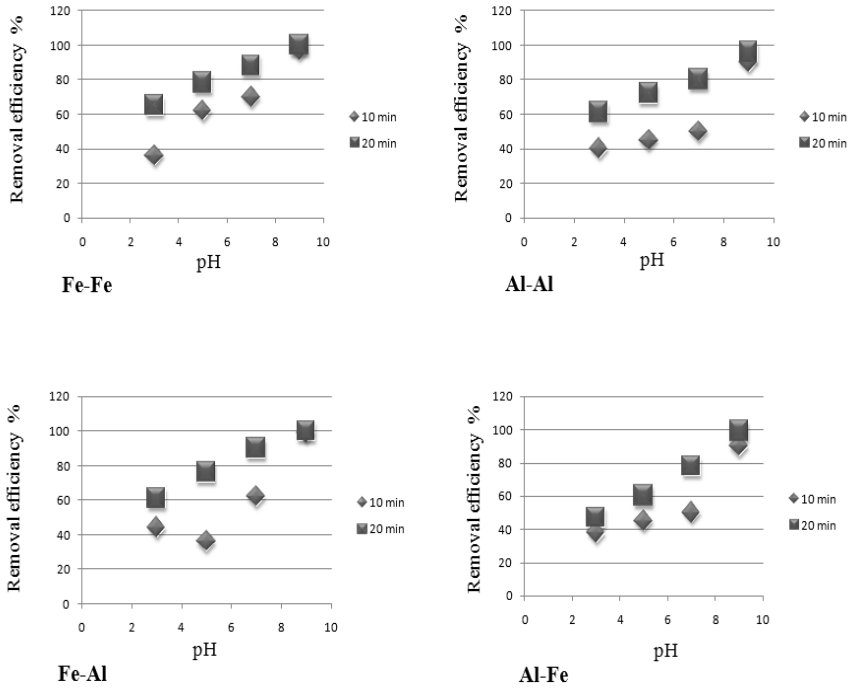


Figure 5: Graph for Nickel removal effeciency for optimized current 1.0A at varying electrode combination and pH values



III. RESULTS AND DISCUSSION

During analysis of electro-plating wastewater it was found that zinc and iron are well below limits of disposal standards and nickel and chromium having significant concentration in wastewater compared with IS: 10500, 1991. In results only treatment of nickel and chromium is considered as part of study. At pH 3.0, wastewater was treated for nickel and chromium removal by applying current in range from 0.5A, 1.0A and 1.5A with time interval of 10 minutes for retention time of 30 minutes, using different combinations such as Fe-Fe, Al-Al, Fe-Al and Al-Fe. Figure 2 shows, with 1.5A current maximum removal of 94.0% was achieved by Fe-Fe, Fe-Al and Al-Al gave 92.0% and 79.0% for Al-Fe removal efficiency for nickel. Figure 3 shows with 1.5A current maximum efficiency was obtained in 20 minutes, using Fe-Fe combination (95.0%); Fe-Al gave 96.0%, Al-Al as 95.0% and Al-Fe 96.0% in 30 minutes. These was achieved as the current increases from 0.5A to 1.5A dissolution of ions and formation of hydroxyl ions takes place, also as the retention time increases the efficiency increases which is application of Faradays Law. Hence at high current and long retention time, removal efficiency of contaminant increases. Material also plays an important role in treatment Fe at anode has proved efficient in heavy metal removal compared to Al at anode. The reasons might be Ferric ions have high affinity compared to aluminates. Therefore at high current 1.5A, long retention time 30 minutes and material anode iron yield efficient results. According to equation eq-1 & eq-2, as retention time and current increases, dissolution of ions from anode increases increasing the cost. Therefore optimisation is necessary for effective removal of contaminants and cost reduction. The current was optimised to 1.0A as the removal efficiency from then was less increased then to 1.5A. The effluent was now analysis for retention time and variation in pH in range 3.0, 5.0, 7.0 and 9.0 for nickel and chromium removal using Fe-Fe, Fe-Al, Al-Al, and Al-Fe electrode combination. Figure 4 & 5 shows, Maximum removal of nickel and chromium was achieved at pH 9.0, using electrode combination of Fe-Fe and Fe-Al, which was 100.0 % in 20 minutes, compared to 99.0% for Al at anode. At pH 5.0, maximum removal efficiency for Ni was 78.0 % for Fe-Fe, 72.0 % for AL-AL, 76.0 % for Fe-Al and 60.0 % for Al-Fe. Whereas for Chromium 97.0 % efficiency was achieved by Fe-Fe, 92.0 % by Al-Fe, 98.0 % by Fe-Al and 98.0% by Al-Fe combination. At pH 7.0, maximum removal efficiency for Ni was 88.0 % for Fe-Fe, 80.0 % for Al-Al, 90.0% for Fe-Al and 78.0% for Al-Fe, whereas for Chromium 100.0 % efficiency was achieved by Fe-Fe, 94.0 % by Al-Fe, 100.0 % by Fe-Al and 100.0 % by Al-Fe combination respectively. The efficiency was higher at pH 9.0 for Fe at anode because, Fe can have good reactivity over range of pH compared to Al which is effective below 6.0 pH. Secondly, iron was preferred over aluminum as the cost of aluminum was four times higher compared to iron. Spacing of the electrode was constructed at 1 cm apart, considering that distance between electrodes affects rate of dissolution of ions and increase in current rate affecting efficiency. The stirring speed also makes significant effect during experimentation; it was kept to be 200 rpm, as excess stirring may destroy flocs formation and Interrelation Bridge between contaminants. Operation cost is sum of eq-1 and eq-2 majorly, current cost of commercial electricity is 10 INR/kWh and material cost of iron is 46 INR/kg, for aluminium is 185 INR/kg which is 4 times higher compared to iron. Hence energy and electrode consumption are considered as major cost for study. Cost for energy and electrode varies from INR 22.6 to 204/m^3 for

Fe at anode in combination as electrode material and for Al at anode cost ranges from 28.5 to 256 INR/m^3 with efficiency less than 95.0 % for nickel and above 95.0 % for chromium. Whereas for optimised condition for pH and current achieves 100.0 % efficiency in less than 20 minutes with Fe-Fe and Fe-Al combination at pH 9.0 and current 1.0A with total cost less than 90.0 INR/m^3compared to Al-Al and Al-Fe more than 100.0 INR/m^3.

IV. CONCLUSION

Results after experimentation showed that electrocoagulation could be used for removal of heavy metals from electro-plating wastewater for effective disposal. Greater removal efficiency occurred at pH 9.0 with 1.0A current in 20 minutes for 100.0 % removal of nickel and chromium. Results also demonstrated the influence of pH, current, and reaction time on removal efficiency with selective iron material at anode.

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