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ELECTROCHEMICAL DEGRADATION OF REMAZOL RED RB 133 USING SACRIFICIAL ELECTRODES

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Abstract

Textile industries generate various types of wastewater depending on the industrial process and the raw materials used such as jute, cotton and animal fibers (wool and silk) and synthetic materials (nylon, polyester and acrylic). Dyeing and printing unit in textile processing industries use large volume of water (ranging from 200 to 250 kilo liter per ton of textiles) and different chemicals, dyes, and complex organic compounds make the textile wastewater very complicated to treat. In recent years, an alternative method to the conventional ones is the Electrochemical Treatment based on the generation of very reactive species such as hydroxyl radicals that oxidize a broad range of organic pollutants non-selectivity and quickly. The study aimed at the degradation of reactive dye by electro-coagulation using iron and aluminium electrodes.

The results showed maximum color removal of 90.59% and COD removal of 54.36% operating at a current density of 176 A/m^2 after electrolysis duration of 10 minutes at optimum pH 7 for *iron electrode. Aluminum electrodes showed maximum color removal of 72.33% and COD removal of 56% after an electrolysis duration of 60 minutes, pH 7 at a current density of 216 A/m^2. At the optimum conditions, the energy consumption, electrode consumption and operating cost to treat a cubic meter of sample found to be less for iron than aluminium electrode. The study concluded that, electro-coagulation proved to be an efficient method for the degradation of reactive red dye using iron electrode.*

Keywords

Aluminum, Electro-Coagulation, Reactive Red, Iron.

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1. Introduction

Industrial increase in urban areas, mainly textile industries is posing a threat to the water bodies as these industries discharge wastewater with various harmful and toxic components, importantly dyes. This degrades the quality as well a quantity of water and makes it unfit for further use (Gupta et al., 2015). Production of wastewater from a textile dye industry is due to the handling operations in employment all through the change of fiber towards textile fabric. It was evaluated that in the scope of 1-15% of color was lost amid coloring process, subsequently these material enterprises deliver substantial amounts of very huge effluents, which are by and large harmful and impervious to damaging activity by typical treatment methods (Neelavannan et al., 2007). Reactive dyes are widely used in textile industries due to their characteristics such as bright color, water fastness, and their simple application techniques with low energy consumption (Mahmoud, 2016).

Wastewater generated from material industries having reactive colors throw serious problem to the environment as the appearance of dyes or color in water appears highly and influences clearness and visual conditions even if the concentration of the dye is little. Reactive dyes cause respiratory plus nasal indications, asthma rhinitis and dermatitis, allergic contact dermatitis. In addition to the above, special impacts have also been encountered in the water environment. Dyes have a very low rate of removal for BOD to COD ratio less than 0.1 (Shyamala et al., 2014). Reactive colors are capable of shaping covalent bonds by way of yarn particle and are considered to be the most efficient and changeless dyes used. They exhibit perfectly fit on whichever cellulose fibre under various temperatures (Ghaly et al., 2014). The elimination of color is thus a challenge towards both the fabric industry plus the wastewater handling amenities that should be treated earlier than its clearance into water bodies.

In the direction of prevention of azo dye amassing in water environment, various strategies are being created to carry out the eradication of these compounds of these compounds from wastewater. These comprise of biological physico-chemical methods such as flocculation combined with flotation, membrane filtration, coagulation, ion-exchange, irradiation treatment method. On the other hand, these strategies are in general unsuccessful in color elimination further costlier too therefore its flexibility is minimum to a broad variety of dye wastewaters (Peralta et al., 2012).

Recently, an alternative method to the customary ones is the Electrochemical Treatment based on the production of especially reactive class such as hydroxyl radicals so as to oxidize a wide range of organic pollutants non-selectivity and rapidly (Neelavannan et al., 2007). The focal points of electro-coagulation include high particle evacuation proficiency, compact treatment ability, comparatively little price and option of complete mechanization. Electrochemical coagulation was achieved using sacrificial anodes like iron and aluminum (Mareiasala et al., 2012).

Since the efficiency of treatment is dye specific, the final choice of the treatment system can be made only after preliminary laboratory tests. Hence the present study is taken up with the objective of assessing the suitability of treatment method for dye degradation in terms of electrochemical treatment using sacrificial electrodes.

2. Materials And Methods

The model dye utilized as a part of this examination was a reactive textile dye Remazol Red RB 133 (RR 133). It is a commercial reactive azo dye employed in cotton textile industry. The basis for selection of the RR 133 dye is the toxicity effect of azo dye to the environment. It is a synthetic organic dye and is selected for the present investigation due to its high solubility in aquatic environment, which is difficult to decolorize by conventional coagulation/flocculation and physical adsorption. It is a Monochlorotriazine –Vinyl Sulphone reactive group and its characteristics and structure are shown in Fig.1.

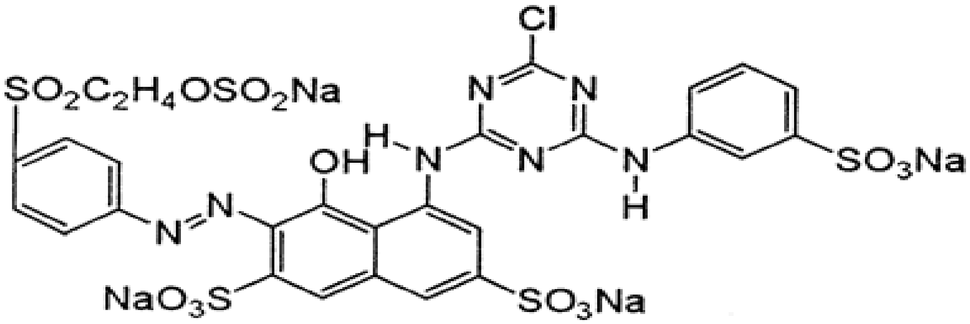

Figure1: *Molecular Structure of the Reactive Dye, Remazol Red RB 133*

During the present investigation, the RR 133 dye was used as received without further purification. The stock solution of the dye was prepared by dissolving exactly weighed 1g of dye in one litre of double distilled water (Mollah et al., 2010, Jovic et al., 2013 and Daneshvar et al., 2006). 100 mg/L concentration of solution was selected for the study with a working volume of 500 mL (Mariana et al., 2004, Rajkumar et al., 2007) which has pH=5.8 and initial COD of 216 mg/L.

2.1 Materials

The experimental set-up is as appeared in Fig. 2 comprised of a borosil glass beaker of 500 ml capacity, in which two electrodes anode and cathode measuring 5cm x 5cm were placed vertical and parallel to each other and connected to a DC power supply (Tektronix). Based on the preliminary investigation 2cm inter-electrode distance was maintained using a head plate throughout the study.

The experiments were carried out with the RR 133 dye solution using iron and aluminium electrodes at room temperature and with constant agitation by means of a magnetic stirrer to prevent concentration slopes. During the experiment, samples were collected at regular time intervals from the reactor and analyzed for different parameters such as COD, color and pH according to the standard methods proposed by APHA (2012). Determination of the percentage color removal of the wastewater was carried out by measuring the absorbance with a spectrophotometer at a wavelength of 510nm (λ_{max}) which was obtained by measuring the RR 133 dye sample at different wavelengths. The wavelength with maximum absorbance was selected. The initial and final weight of the anodes was also measured during the experiment. The optimum conditions for effective removal of color, COD and energy consumption have been studied in batch reactor for each of the electrode used.

The percentage of color removal and COD removal was determined using the following formulas;

$$Color\ removal\ (\%) = \frac{Abs(max) - Abs(t)}{Abs(max)} x100 \quad (1)$$

Where, Abs_{max} = Absorbance of the initial dye sample at 510nm.

Abs_t = Absorbance of the dye samples collected at regular time intervals, t, minutes

$$CODremoval\ (\%) = \frac{COD(0) - COD(t)}{COD\ (0)} x100 \quad (2)$$

Where, COD_0= COD of raw sample in mg/L

COD_t = COD removed in mg/L at regular intervals of time, minutes.

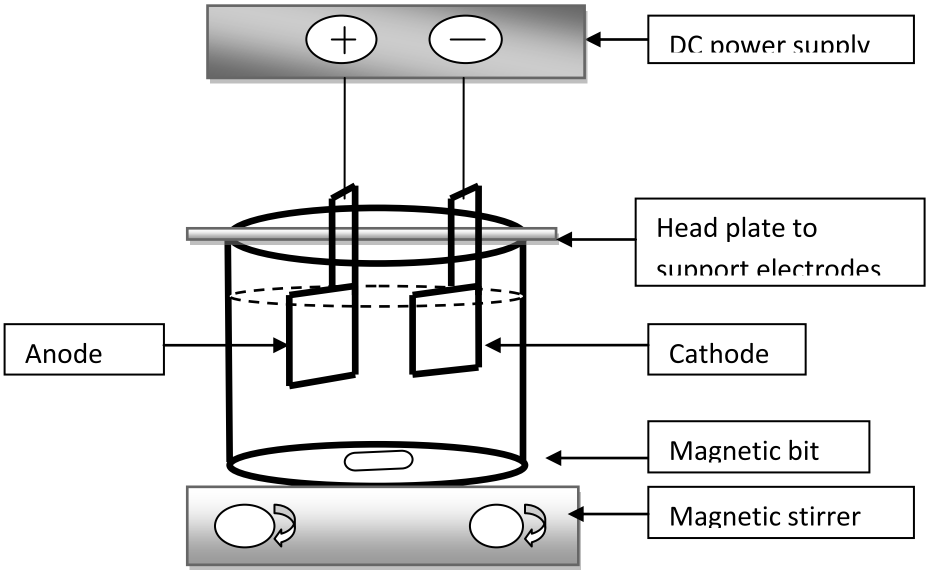

Figure 2: *Schematic Drawing of an Electrochemical Cell*

Color concentrations were decided utilizing a working bend by plotting the absorbance versus known concentrations at λmax (Can et al., 2003, Rezaee et al., 2008). The anodic proficiency of electrochemical treatment has been calculated in terms of kg COD removed per hour per ampere per square meter area of electrode, kg COD/h/A/m^2.

$$AnodicEfficiency = \frac{\Delta\ COD}{I * t * Ae * 10^{\wedge}6} \quad (3)$$

Where, ΔCOD is the COD removed in time t in hour, I current in amperes, A_e is the area of electrode in m^2.

2.2 Electrochemical Degradation Studies

Electrochemical degradation studies were carried out by determining the optimum electrolyte concentration, optimum electrolysis duration, optimum current density and optimum pH for the reactive dye solution using iron and aluminium electrodes respectively.

2.3 Electrical Parameters

Specific electrical energy consumption is the amount of electrical energy consumed per unit mass of organic load and was calculated in terms of various measurements as given below (Martinez et al., 2009). The specific energy parameters such as energy consumption per volume of treated effluent (kWh/m^3), dye mass (kWh/kg of dye), anode mass (kWh/kg of Fe) destroyed (Martinez et al., 2009, Basiriparsa et al., 2009) were also calculated. Two specific Figures of Merit are presented:

2.3.1 The Electrical Energy Per Unit Mass(E_{EM}/Kwh/Kg) is defined as the electrical energy in kilowatt hours (kWh) required to bring about the degradation of a unit mass (1kg) of a contaminant C in polluted water or air. For high organic concentrations, where the removal rate is phenomenologically zero order with respect to the substance [C] of interest:

$$Energyconsumption, \frac{kWh}{kg} = \frac{I*V*t*1000}{60*Vs*(Ci-Cf)} \qquad (4)$$

Where,

P= Rated power (Watts) [P= (I * V), I= current in amps, V=voltage in volts], t= time (minute), Vs= volume (L) treated, C_i and C_f= initial and final concentrations of [C] (mg/L).

2.3.2 Electrical Energy Per Order (E_{EO}/Kwh/M^3 /Order) is defined as electrical energy in kilowatt hours (kW h) required to bring about the degradation of a contaminant, C by one order of magnitude in 1 m^3 (1000 L)of contaminated water or air. For low organic concentrations, where the removal rate is first order with respect to the substance [C] of interest, the E_{EO} is given by (Hazira Khan, 2010, Malpass, 2008),

$$Energyconsumption, \frac{\frac{kWh}{m3}}{order} = \frac{I * V * (\frac{t}{60})}{Vs * Log(\frac{Ci}{Cf})} \qquad (5)$$

2.3.3 Energy Consumption Per Cubic Meter Of Sample

$$EnergyConsumption, \frac{kWh}{m3} = \frac{I * V * \left(\frac{t}{60}\right)}{Vs} \qquad (6)$$

Where, I = Current, amps, V= Voltage, volts, t= Time, minutes, V_s= Sample volume, L.

2.3.4 Energy Consumption Per Kg Of Anode

$$Energyconsumption, \frac{kWh}{kg} of anode = \frac{I * V * (\frac{t}{60})}{\Delta Anode} \qquad (7)$$

Where, Δ Anode= Change of anode mass in grams.

2.3.5 Energy Consumption Per Kg Of Dye

$$Energyconsumption, \frac{kWh}{kg} of dye = \frac{I * V * (\frac{t}{60})}{\Delta dye} \qquad (8)$$

Where, ΔDye=Change in dye concentration, grams.

2.4 Operating Cost

The execution of an electrically worked handle like electrochemical coagulation subordinate on electrical vitality utilization which straightforwardly influences the working taken a toll of the handle. In this, for the financial examination, vitality and anode fabric costs have been taken into account as major fetched things in the calculation of the working fetched (Eq. 9) (Bayramoglu et al., 2004; Can et al., 2006).

$$\text{Operatingcost} = a\, C_{energy} + b\, C_{electrode} \qquad (9)$$

Where,

$$C_{energy} = \text{Energy Consumption}/m^3.$$

$$\text{Celectrode} = \frac{I * t * M}{z * F * V} \qquad (9a)$$

Where, I=Current in Amps, t= Time in seconds, M= Molecular weight of electrode (g/mol), z= Valency, F=Faradays Constant (96485 Coulomb/mol), V= volume in cubic meter.

a= Electrical energy price Rs.6.25 kWh (Bangalore Electricity Supply Company Ltd)

b=Electrode material price in kg for iron and aluminium, as per Indian market value

(Iron= Rs.49/- per kg, Aluminium = Rs.125/- per kg).

3. Results and Discussions

3.1 Electrochemical Degradation Studies

3.1.1 Effect of Conductivity

The experiments were carried out for varying dosage of NaCl at a fixed current density for both electrodes to check the color removal efficiency by drawing the samples at regular intervals until maximum color removal was obtained and the same is presented in Fig.3.

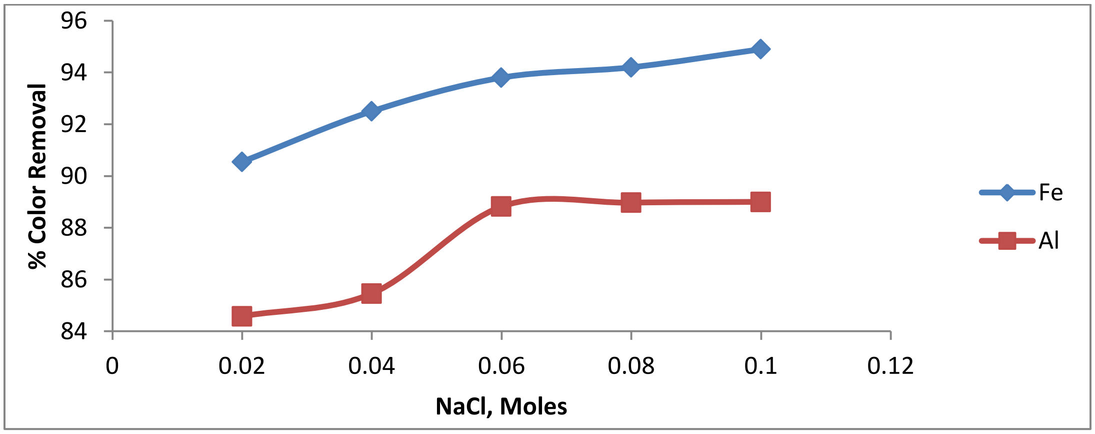

Figure 3: *Color Removal Efficiency at Various Dosages of NaCl (Fe=Iron, Al=Aluminum)*

Fig. 3 implicit that, raise in the concentration of NaCl quickened degradation speed, empowering the decolorisation effectiveness of RR 133 dye. At 0.02M of NaCl maximum color removal of 90.55% and 84%, for iron and aluminum electrodes was achieved.

Further increase in the conductivity of dye solutions does not revealed substantial incremental outcome on color removal efficiency. From the observations, it is clear that, increasing the chloride concentration increases the color removal because of the increase of majority transfer of chloride ions to the electrode face and also augmented diffusion in the diffusion layer of the electrode. Because of which, more quantity of chlorine/hypochlorite will be produced. Therefore, the scale of color removal increases (Rajkumar et al., 2007).

This agrees with other literatures stated by Rajkumar et.al (2007), Prakash et.al (2011) as, operation of rigorous restrictions for total dissolved solids concentration for the treated wastewater by numerous administrative establishments as total dissolved solids increases with increase in NaCl concentration. The degradation studies were conducted for the RR 133 dye solution with a conductivity of 2.4 mS.

3.1.2 Electrolysis Duration (ED)/ Electrolysis Time

ED impacts the treatment proficiency of the electrochemical process. The initial set of experiments was conducted at 2.4mS conductivity, 2cm inter-electrode distance and at the existing pH of 5.8. From the Fig.4 it is depicted that, using iron electrode, the color elimination efficiency amplified with an increase in the electrolysis time. It is understood that the maximum color removal of 90.24% was achieved at 10 minutes ED for iron electrode.

Fig. 5 shows that, color removal of 83.92% was achieved at 30 minuteswhereas 94.95% was achieved at 60 minutes of ED for aluminum electrode which may be due to the limited floc formation. Daneshvar et al., (2006) reported the similar findings. Color removal of 94.95% was achieved with 60 minutes, which was considered as optimum ED.

Later, a slight decrease was observed with both electrodes, which may be due to the exhaustion of hypochlorite and free chlorine generation in-situ in the reactor. Similar findings were reported by Sheng et al., (1994). Secondly, due to deposition of toxic metals/materials on the anode which might have further prevented color removal. The percentage of color removal efficiency depends directly on the concentration of hydroxyl and metal ions produced on the electrodes produced by the dissolution of the electrodes (Daneshvar et al., 2006).

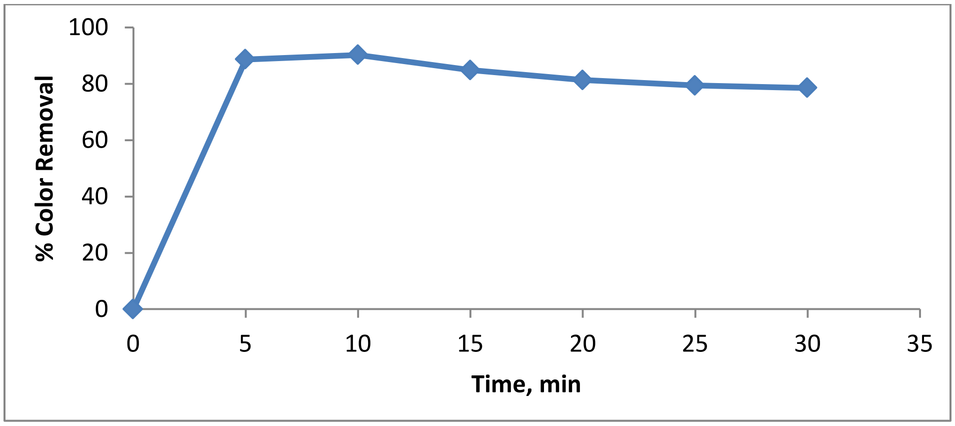

Figure 4: *Electrolysis Duration for Iron Electrode.*

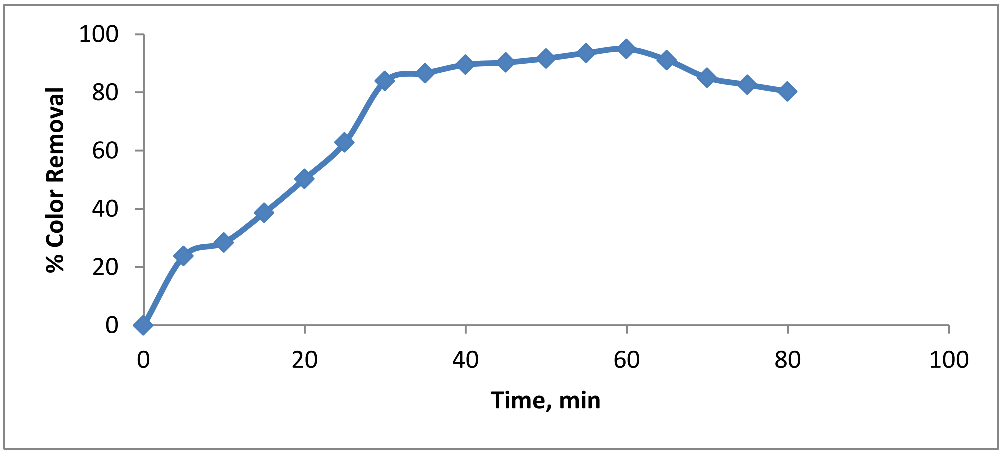

Figure 5: *Electrolysis Duration for Aluminum Electrode.*

3.1.3 Effect of Current Density (CD)

To examine the impact of current thickness on the effectiveness of color and COD removal, electro-coagulation process was carried out at varying current densities of56 A/m^2, 96 A/m^2, 136 A/m^2, 176 A/m^2, 216 A/m^{2}for iron and including 256 A/m^{2}for aluminium electrodes (0.14 A, 0.24 A, 0.34 A, 0.44 A, 0.54 A and 0.64 A). Based on the previous experiments 10 minutes of optimum ED was maintained for iron electrode. The experimental results of percentage color and COD removal at different CD for iron electrode are presented in Fig. 6. The results are 55.28%, 60.45%, 68.82%, 73.12%, 76.26% color removal and COD removal of 28.68%, 40%, 44.5%, 53.34% and 58.44% at current densities varied from 56 A/m^{2}to 216 A/m^2 respectively.

Fig. 7 presents the percentage color and COD removal at different current densities for aluminium electrode. The color removal efficiency was 34.62%, 48.98%, 60.12%, 78.19%, 80.14% and 73.86% and COD removal was 33%, 38%, 41%, 45%, 52% and 48% for the current densities of56 A/m^2, 96 A/m^2, 136 A/m^2, 176 A/m^2, 216 A/m^{2}and 256 A/m^{2}respectively for aluminium electrodes at 60 minutes of ED.

Fig.8 and Fig.9 shows the color and COD removal efficiencies at 10 minutes ED at regular intervals of 2 minutes for different current densities respectively for iron electrode.

Fig. 10 and Fig. 11 exhibits the removal efficiencies at regular time intervals of 10 minutes till 60 minutes of ED at different current densities for aluminium electrode.

It can be watched that color and COD evacuation effectiveness expanded slowly with expanding connected current thickness. This is since of the expanded rate of era of oxidants such as chlorine/hypochlorite and hydroxyl radicals at higher current densities. By expanding the current thickness, the anodic disintegration of metal will be expanded coming about in a more prominent sum of accelerate produced in the arrangement and the time required for coagulation is diminished (Raju et al., 2008).

In the show consider, in spite of the fact that the rate of expulsion is speedier for both color and COD by increasing the CD from 56 to 216 A/ m^2 but observed with no appreciable change in removal rate beyond 176 A/m^2 current density for iron electrode.

From the Fig. 12 it is observed that, up to a CD of 216 A/$m^2$the degradation efficiency in terms of color and COD removal increased linearly for aluminium electrode, later the degradation efficiency decreased which may be due to the restricted sum of broken down cathodes participation in the formation of hydroxypolymeric species which reduced floc mass (Can et al., 2003, Mollah M Y A et al., 2010).

It is, be that as it may, prudent to constrain the current thickness in arrange to dodge over the top advancement of hydrogen and other gasses as well as to play down other antagonistic impact counting higher fetched of operation. Increase in electrolysis process beyond optimal range causes the dents over the anode plate causing the reduction in the removal efficiency. Similar findings were reported by Kobya et al., (2009), Krishna et al., (2012), Chen (2004). To keep the electrical fetched of operation less and the end-solution after EC less saline, current density of 176 A/m^2 was considered as optimum for iron and 216 A/m^2 for aluminium electrode.

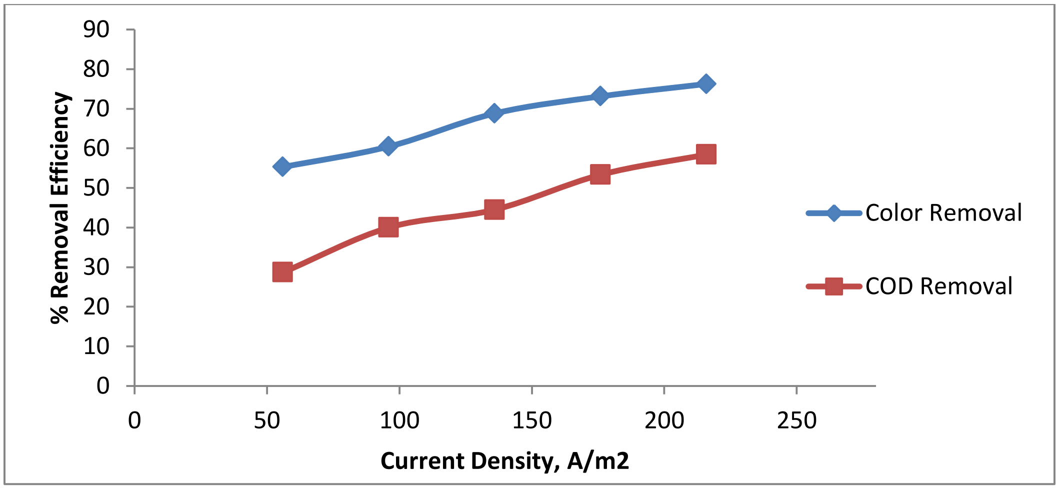

Figure 6: *Color and COD Removal at Different Current Densities, iron*

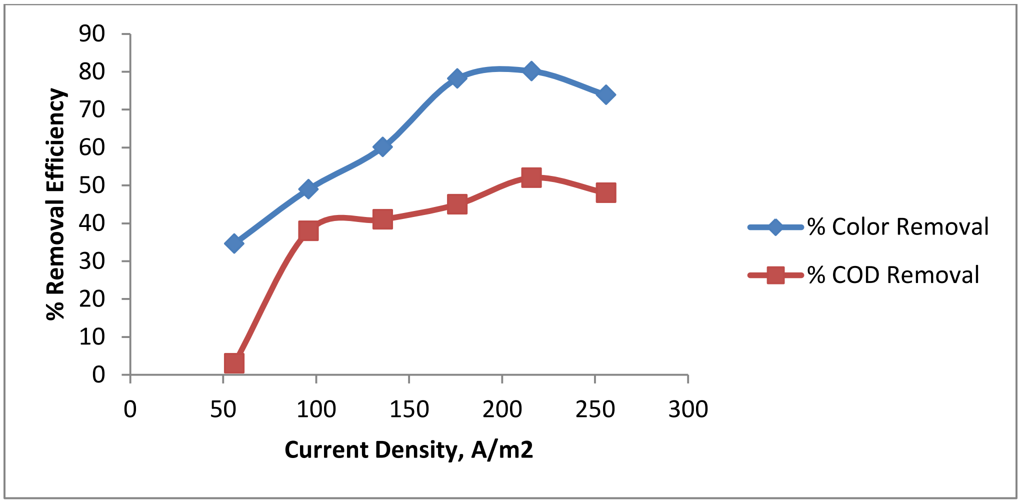

Figure 7: *Color and COD Removal at Different Current Densities using Aluminum*

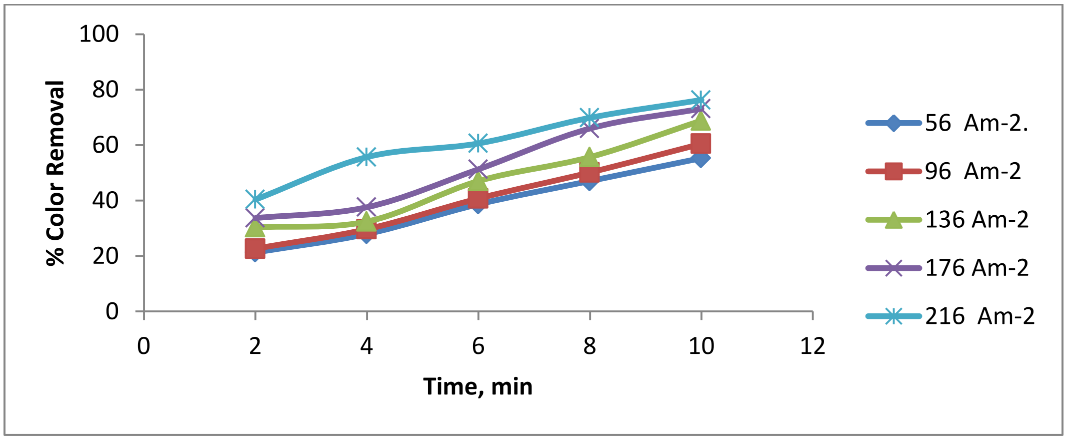

Figure 8: *% Variation of Color at Varying Current Density at Time Intervals for Iron Electrode*

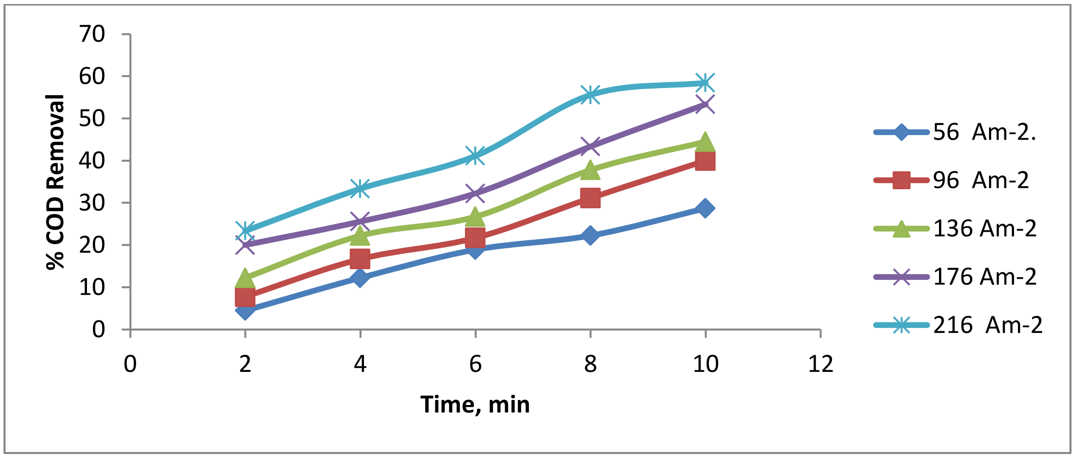

Figure 9: *% Variation of COD at Varying Current Density at Regular Time Intervals for Iron Electrode.*

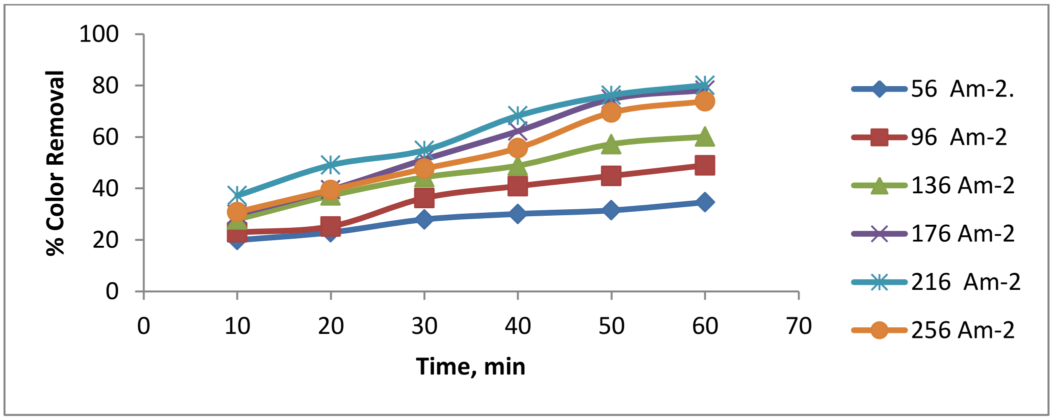

Figure 10: *Percentage Color Removal at Varying Current Densities at Regular Time Intervals for Aluminum Electrode.*

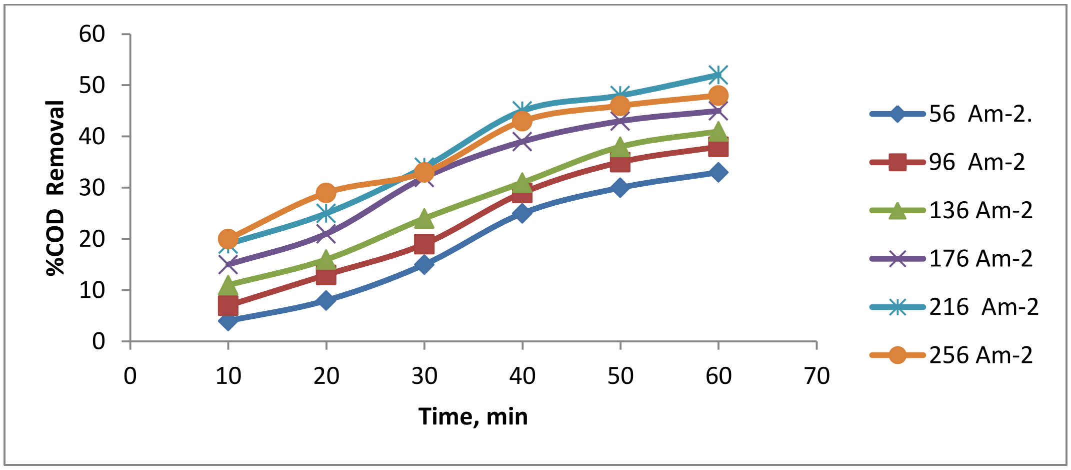

Figure 11: *Percentage COD Removal at Varying Current Densities at Regular Time Intervals for Aluminum Electrode.*

3.1.4 Effect of Initial pH

It has been built up that the influent pH is a critical parameter affecting the execution of the EC process (Daneshvar et.al. 2006). To examine its effect, individual experiments were carried out at initial pH of 3, 5, 7 and 9. The pH of wastewater was adjusted by adding sodium hydroxide or sulphuric acid to get the desired initial pH. Based on the previous experiment the ED was fixed at 10 minute and CD of 176 A/m^{2}for iron electrode. ED of 60 minute and CD of 216 A/m^{2}for aluminium electrodes.

Fig.12 and Fig.13 reveals that, color removal efficiency was 92.96%, 91.85%, 90.59% and 91.85% and COD removal was 52.16%, 50.00% 54.36% and 51% at pH 3, 5, 7 and 9 respectively. The color and COD reduction are >90% and >50% at all pH values but with varying pattern of removal efficiency with respect to regular time intervals. During the experiment at pH of 3, increase in color removal was observed at a time interval of 6 minutes and at pH 7 it was observed at 8 minutes.

Fig 14 reveals that pH of the dye solution increases during the prepare which depends on the sort of anode fabric and introductory pH (Kobya et al., 2003). It may moreover be famous that the arrangement pH moved to fundamental run which may be ascribed to the cathodic diminishment of water atoms and chemical disintegration of press cathode expanded the pH esteem (Muthukumar et al., 2007).

The findings by Muthukumar et al., (2007) confirms that, “superior evacuation of colors was watched between pH 6.0 and 9.0. The Fe particles discharged from cathode shape particular oxy-hydroxy species such as $FeOH^+$, $FeOH^{2+}$, Fe $(OH)^{2+}$, $Fe(OH)_2$, $Fe(OH)_3$, $Fe(OH)_4^-$and FeO(OH). The metal hydroxy species have articulated propensity to associated with hydroxyl bunches of adjoining particles and shapes coagulum. The action of Fe $(OH)_2$ and $Fe(OH)_3$ species will be overwhelming between pH 7.0 and 8.5". This shows that pH 7 is favorable for the treatment as it is achieving the same removal efficiency as pH 3 at the end of ED. Kobya et al., (2003) reported that, iron is more efficient in neutral and alkaline medium, especially between $6 < pH < 9$.

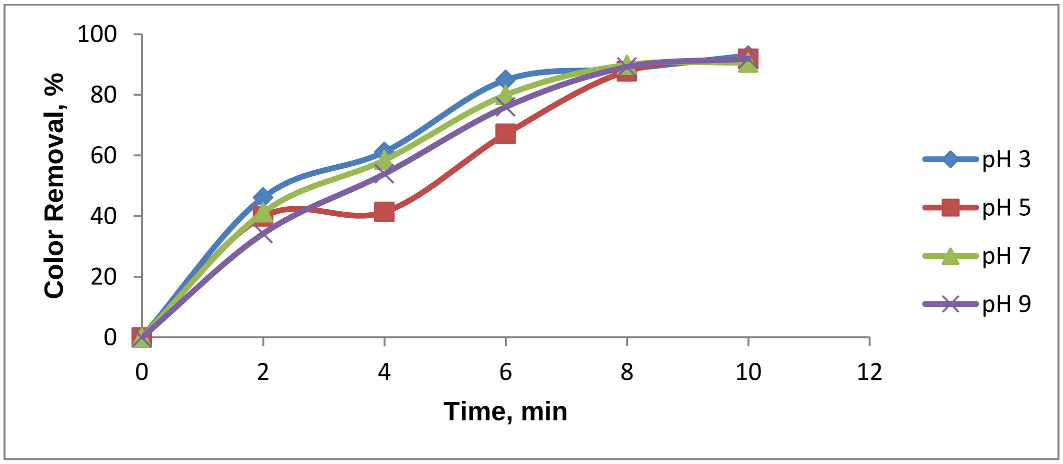

Figure 12: *Variation of Color at Different Initial pH for Iron Electrode.*

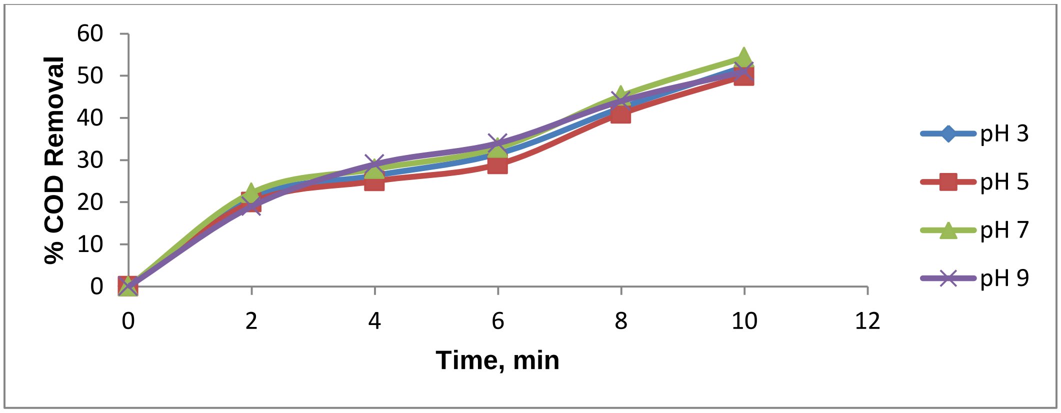

Figure13: *Variation of COD at Different Initial pH for Iron Electrode.*

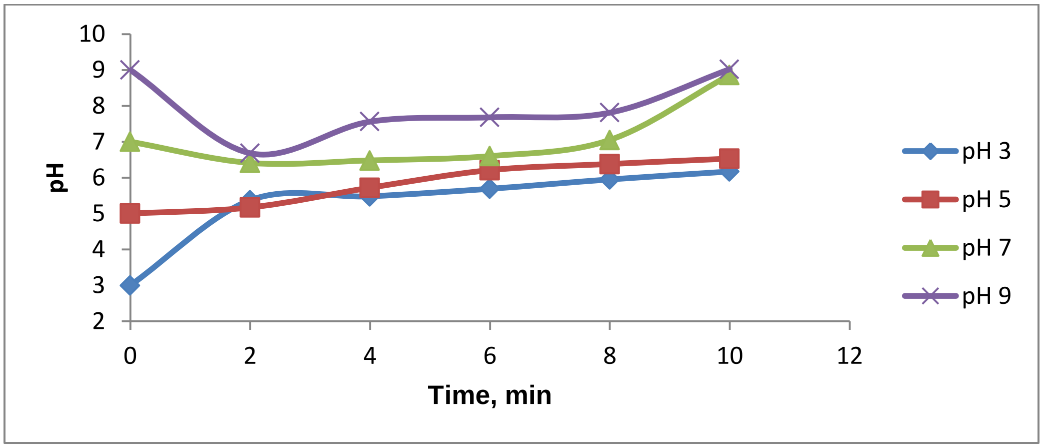

Figure 14: *Variation of Initial pH at Different Time Interval with Iron Electrode.*

As seen from Fig. 15 and Fig. 16 there was a considerable effect on color removal with varying pH using aluminium electrode. The maximum color removal of 74.76% and 72.33% observed at pH of 3 and 7. The most noteworthy evacuation efficiencies have been gotten with aluminum in acidic medium with pH less than 6 for Kobya et al., (2003) and pH 6.5 for Mollaha MYA et al., (2010). At pH of 5 and 9 the color removal was 47.47% and 69.71% respectively. This shows that pH 3 and 7 are favorable for the treatment of dye solution. It is observed that COD removal was 51%, 52%, 56% and 53% which does not indicate significant variations with each other at different initial pH of 3, 5, 7 and 9 respectively. As discussed earlier, the initial pH varies with the process changes. With respect to aluminum, the last pH is higher for introductory pH < 8, and over this point the last pH is lower as indicated in Fig. 17 and it is observed that, the initial pH 3, 5, 7 and 9 for aluminum electrode changed to 9, 9.44, 9.36 and 8.95 at the end of reaction respectively.

The expansion of pH at acidic range was credited to hydrogen advancement at cathodes. Other than hydrogen development, the arrangement of $Al(OH)_3$ close to the anode would discharge H^+ leading to diminishing of pH. Concerning the pH diminish at soluble conditions, it can be the after effect of development of hydroxide accelerates with different cations, the arrangement of $Al(OH)_4^-$ (Chen et.al. 2004).

Two fundamental components are by and large considered: precipitation for pH lower than 4 and adsorption for higher pH. Adsorption may continue on $Al(OH)_3$ or on the monomeric $Al(OH)_4^-$ anion depending on the color chemical structure (Essadki et.al. 2008). This recommends that the color precipitation handle is essentially mindful of the tall decolorisation productivity, and adsorption of the color polymeric species colloidal accelerates by $Al(OH)_3$ flocs has a more auxiliary impact. Hence pH 7 was considered as favourable for the process.

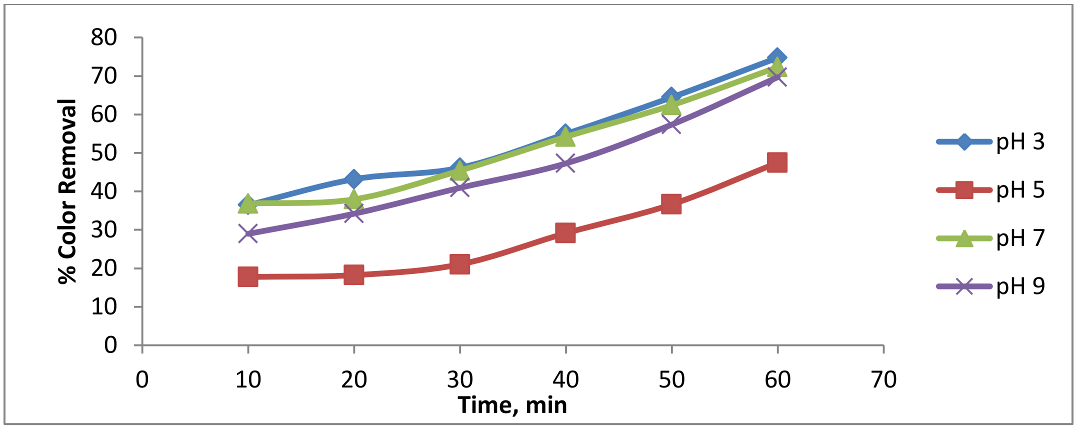

Figure 15: % *Color Removal at Different Initial pH for Aluminum Electrode.*

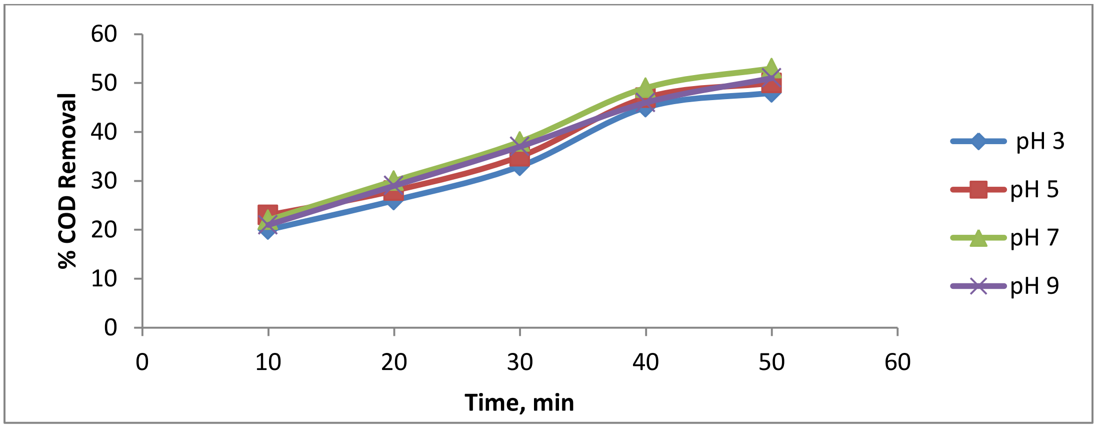

Figure 16: *% COD Removal at Different Initial pH for Aluminum Electrode.*

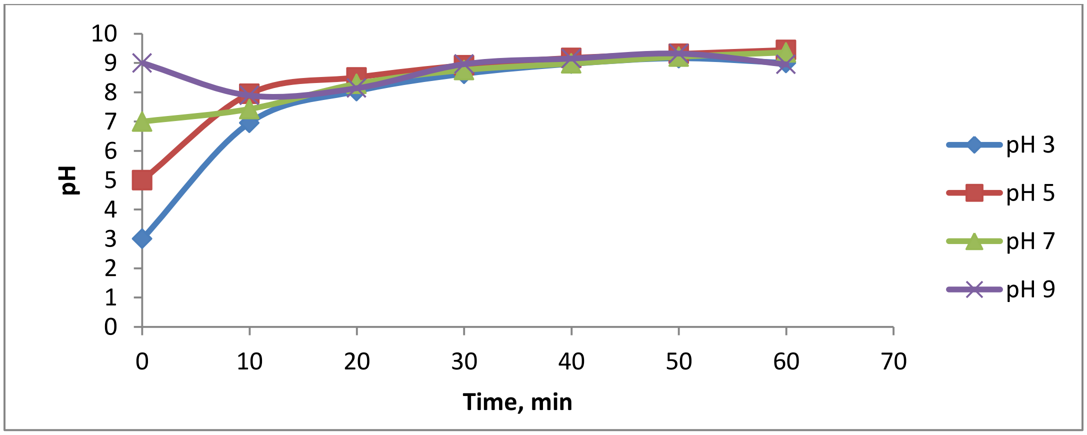

Figure 17: *pH Variation at different Initial pH for Aluminum Electrode.*

3.2 Comparative Study between Iron and Aluminum Electrode

3.2.1 Quantitative Analysis

In this aspect quantitative analysis was done for both electrodes, which were used as electrodes during electrolysis. From the Table 1, it is observed that weight of anode and cathode indicates the loss of metallic surface during the process.

Table 1: *Quantitative Analysis of Iron and Aluminum Electrodes before and after Electrolysis.*

Electrodes	Anode/Cathode	Electrode Initial Weight (g)	Electrode Final Weight (g)	Difference in Weight (+ gain & - loss)
Iron	Anode	75.9493	75.8877	-0.0616
	Cathode	75.0758	75.0735	-0.0023
Aluminum	Anode	26.3681	26.1325	-0.2356
	Cathode	26.8138	26.7863	-0.0275

3.2.2 Operating Cost

The operating cost consist of electrical cost and anode consumptions and is calculated at optimum conditions of 10 minute ED, 176 A/m^2 and pH 7 for iron electrode, and 60 minute ED, 216 A/m^2 at pH 7for aluminum electrode and is presented in Table2. The operating cost for aluminum found to be 10 times higher than iron electrode because of higher energy consumption and electrolysis duration. It is understood that, operating costs will emphatically impact the choice of the type of sacrificial anode material for given reactive dye.

Table 2: *Operating Cost at Optimum Operating Conditions*

Electrode	Energy Consumption (1)	Energy Cost (Rs)(2)	Electrode Consumption (Rs)(3)	Electrode Cost (Rs) (4)	Operation Cost (Rs) (2)+(4)
Iron	1.13 kWh/m^3	7.06	0.15 kg/m^3	7.35	14.41
	9.62 kWh/kg COD	60.13	1.30 kg/kg COD	63.7	123.83
	12.47 kWh/kg dye	77.94	1.69 kg/kg dye	82.81	160.75
Aluminum	11.34 kWh/m^3	70.87	0.36 kg/m^3	45	115.87
	93.75 kWh/kg COD	585.94	3.00 kg/kg COD	375	960.94
	156.78 kWh/kg dye	979.87	5.01 kg/kg dye	626.25	1606.12

(*Energy Cost= Rs.6.25/kWh, Iron= Rs.49/kg, Aluminum=Rs.125/kg)

3.2.3 Energy Consumption

The energy consumption in kilowatt hour (kWh) for various electrical parameters such as to treat a cubic meter of sample, kg of COD, kg of electrode, kg of dye and energy consumption per order of color and COD removal for iron and aluminium electrodes were determined and the values are shown in Table 3. It is known from the table that, energy consumption for aluminium electrode is higher than iron electrodes.

Table 3: *Energy Consumption for Iron and Aluminum Electrodes*

Current Density A/m^2	pH	Voltage (V)	Anode Dissolution (mg)	Energy Consumption, kWh					
				per cubic meter sample	per kg COD	per kg Electrode	per kg Dye	per order/color	per order/COD
176	7	7.7	61.6	1.13	9.62	9.17	12.47	1.10	3.32
216	7	10.5	0.2356	11.34	93.75	24.06621	156.78	20.32	31.81

3.2.4 Efficiency of Electrodes

The comparison between iron and aluminum electrodes made on the basis of optimum operating conditions, color and COD removal rate, energy consumption and operating cost. Table 4 shows the comparison of performance of electrodes based on the above parameters. It can be noted from the Table 4, that, the cost of iron electrode was cheaper compared to aluminum electrode. The outcome demonstrates that iron found to be economical than aluminum in the field of color and COD removal. This may be due to the contrasts in the components of COD elimination for the iron and aluminum electrodes.

Table 4: *Efficiency Comparison between the Electrodes.*

Parameters	Iron Electrode	Aluminum Electrode
ED (minute)	10	60
CD (A/m^2)	176	216
pH	7	7
Color removal (%)	90.59	72.33
COD removal (%)	54.36	56
Cost per kg of electrode	49	125
Operation cost per m^3 of sample	14.41	115.87
Operation cost per kg of COD	123.83	960.94
Operation cost per kg of dye	160.75	1606.12

4. Conclusions

The following conclusions are drawn based on results;

- EC using iron electrodes showed maximum color removal of 90.56% and COD removal of 54.36%, at optimum conditions of electrolysis duration of 10 minutes, pH 7 and at a current density of 176 A/m^2.
- EC using aluminum electrodes showed maximum color removal of 72.33% and COD removal of 56% at optimum electrolysis duration of 60 minutes, pH 7 at a current density of 216 A/m^2.
- Iron found to be superior to aluminum electrode, because aluminum exhibits only electro-coagulation, while the iron electrodes exhibit collective effect of electro-coagulation and electro-oxidation.
- Further, large quantity of sludge generated with the electrodes requires post treatment facilities and disposal which increases the cost of treatment.
- Further investigations on combination of electrochemical and biological treatment can be carried out to meet the effluent discharge standards

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