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# Separation of Pollutants from Restaurant Wastewater by Electrocoagulation

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**Abstract:** Of late, electrocoagulation has been widely used to treat a wide variety of wastewaters, including textile, dye, electroplating, chemical mechanical polishing wastewaters, etc. Excessive coagulant material may be avoided by electrocoagulation. The contaminants present in wastewaters are maintained in solution by electrical charges. When metal ions of opposite electric charge, provided by an electrocoagulation system, may become unstable and precipitate in a form that is usually very stable. The present work involves the treatment of nearby restaurant effluent in Surat, Gujarat, India. Two different electrodes, aluminum and iron, are used for electrocoagulation. The effect of applied voltage and time of electrolysis on various parameters—such as conductivity, COD, TDS, and turbidity are studied. The removal efficiency of COD is found to be between 50–72% and the optimum time is between 15–30 minutes. Electrocoagulation proved to be a process which could neutralize pH significantly. The major impact of change in electrode is considered and aluminum is found to be better than iron in many respects. The operating cost is estimated from the power cost and cost of electrode material.

**Keywords:** Electrocoagulation, chemical oxygen demand (COD), turbidity, NTU, wastewater

## INTRODUCTION

There are chains of restaurants and fast food joints in India and they use huge quantities of water everyday for cooking and washing purposes. With the

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pollution norms getting stricter, day-by-day care needs to be taken to ensure that the pollutants are within permissible limits before releasing them to drain. Otherwise also the collection and treatment works are a burden to municipalities. The oil and grease content generate an extremely foul odor due to fermentation. Hence it is the responsibility of the restaurant owner to install such treatment facilities which will do away with such problems. With regards to this the electrocoagulation system has been considered. It is important that such facilities must be efficient, small in size, and should not cause any food contamination. It should also have low installation, operating and maintenance costs and should be user friendly (1). Chemical coagulation encounters dual problems of food contamination and low efficiency. The biological process requires skilled labor which will be an extra financial burden to restaurant owners (2).

Electrocoagulation (EC) has been extensively tried/used efficiently to treat many waters and wastewaters including potable water, textile wastewater, dyestuff wastewater, oil and shale wastewater, etc. (1–43) and also integrated with other processes (44–47) for the last five years. This shows the importance of the EC process in the treatment of wastewaters. But application of EC to separate pollutants from restaurant/hotel wastewaters is feeble (2). Hence, the present work is aimed in this direction, treating wastewater in a nearby restaurant. Electrocoagulation involves three successive stages (3):

1. Formation of coagulants by electrolytic oxidation of the "sacrificial electrode",
2. Destabilization of the contaminants, particulate suspension, and breaking of emulsions, and
3. Aggregation of destabilized phases to form flocs.

The EC process involves the generation of coagulants *in-situ* by passing electricity through iron or aluminum electrodes. At anode, oxidation reaction takes place and metal ions are formed, and hydrogen gas is released from the cathode. The electrodes can be arranged in a monopolar or a bipolar assembly (11). Electrode assembly is the most important part of electrocoagulation process. In most of the cases reported in literature, aluminum and iron are used as electrodes for the process because they are very cheap and easily available. In the present work too aluminum and iron electrodes are used to treat the nearby restaurant wastewater.

## MATERIALS AND METHOD

The EC experimental set-up is shown in Fig. 1. The electrocoagulation cell consists of a 500 mL beaker. Wastewater of the volume of 300 mL is taken in the beaker for treatment every time. The iron and aluminum electrodes

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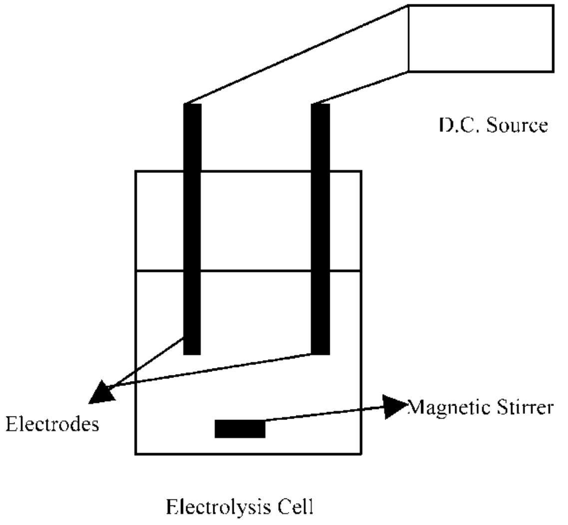


*Figure 1.* Electrocoagulation experimental setup.

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are dipped in the beaker and the spacing between the two electrodes is kept at 5 cm. The effective surface area of electrodes undergoing electrocoagulation is 35.4 $cm^2$. The two electrodes are connected in monopolar mode in the cell. A magnetic stirrer is used to ensure that the composition of the solution remains the same throughout. Wastewater is collected from a nearby restaurant and experiments are conducted to study the effects on various parameters by changing the variables. A batch process is used for all the analysis. All the samples are allowed to settle for one hour before analysis and filtration is done using filter papers. Chemical oxygen demand (COD) is measured using batch reactor following the standard methods (48).

## RESULTS AND DISCUSSION

EC is a complex process occurring via serial steps such as electrolytic reactions at electrode surfaces, formation of coagulants in aqueous phase, adsorption of soluble or colloidal pollutants on coagulants which are removed by sedimentation or flotation (1).

### Iron Electrodes

In the case of iron electrodes, two mechanisms for the production of metal hydroxide have been proposed (1, 3, 15):

Mechanism 1

*Anode*

$$4Fe \longrightarrow 4Fe^{2+} + 8e^-$$

$$4Fe^{2+} + 10H_2O + O_2 \longrightarrow 4Fe(OH)_3 + 8H^+$$

*Cathode*

$$8H^+ + 8e^- \longrightarrow 4H_2$$

*Overall*

$$4Fe + 10H_2O + O_2 \longrightarrow 4Fe(OH)_3 + 4H_2$$

Mechanism 2

*Anode*

$$Fe \longrightarrow Fe^{2+} + 2e^-$$

$$Fe^{2+} + 2(OH)^- \longrightarrow Fe(OH)_2$$

*Cathode*

$$2H_2O + 2e^- \longrightarrow 2(OH)^- + H_2$$

*Overall*

$$Fe + 2H_2O \longrightarrow Fe(OH)_2 + H_2$$

When the voltage is applied to the wastewater, the solution slowly turns colorless as the coagulated flocs slowly settles down. The insoluble metal hydroxides of iron may remove pollutants by surface complexation or electrostatic attraction. In surface complexation it is assumed that the pollutant can act as the ligand to bind a hydrous iron moiety. In electrostatic attraction, the hydroxide, iron oxide particle containing of apparent positive and negative charge, attract the oppositely charged pollution species and remove them from solution (3, 15).

## Aluminum Electrodes

In case of aluminum electrodes, the observations of the experiments are as follows:

1. The bubbles appear at one of the electrodes as the voltage is applied.
2. The anode slowly starts to dissolve in the sample solution.
3. A translucent white precipitate begins to form.

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4. White translucent flocs begin to settle rendering the solution clear and transparent.

One major problem that occurs during the process is that a layer of white precipitate forms on the surface of the electrodes and this hinders the process of electrocoagulation. This problem can be solved by brushing the electrodes from time to time during the process and also by stirring the solution continuously. The mechanism for the process is that aluminum anode produces the cationic monomeric species such as $Al^{3+}$ and Al $(OH)_2^+$ and finally polymerizes to $Al_n(OH)_{3n}$ according to the following reactions (2, 3, 5):

Mechanism:

$$Al \longrightarrow Al^{3+} + 3e^-$$

$$Al^{3+} + 3H_2O \longrightarrow Al(OH)_3 + 3H^+$$

$$n\ Al(OH)_3 \longrightarrow Al_n(OH)_{3n}$$

## Restaurant Wastewater Characteristics

Restaurant wastewater is the water that is used mostly for cooking and washing utensils, etc. It is the water collected from kitchen drainage that may include bakery items and all food preparations. Food served at different times of the day is different and there is a special cuisine for different days. The composition of wastewater varies from time to time and from day-to-day. Most of the times proper collection channels for wastewaters are not available. So, it is very difficult for the meaningful characterization of samples collected as initial parameters change. To overcome a these problems a preliminary analysis is made and finally 10 L of water collected from different points of the drain system. The characteristics of the wastewater, collected from a nearby restaurant, are given in Table 1. Most of the samples are in neutral pH range. Mixed samples are taken for EC and after electrocoagulation of the sample; it is analyzed for conductivity, total dissolved solids (TDS), and turbidity.

The effect of change of operating variables on the performance of the EC process is analyzed. Both the electrode materials, iron and aluminum, are almost equally effective in general. Most of the pollutants are removed in the process.

***Table 1.*** Characteristics of restaurant wastewater

| | |
|---|---|
| Number of samples | 30 |
| COD (mg/L) | 622–2348 |
| Conductivity (mS/cm) | 0.886–0.934 |
| pH | 6.05–8.01 |
| TDS $\times 10^{-3}$ (mg/L) | 0.634–0.712 |
| Turbidity (NTU) | 25–30 |

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## Effect of Voltage on Conductivity, Turbidity and COD

As shown in Fig. 2, the rate of decrease of conductivity for both the electrodes is almost the same. Aluminum electrode decreases the conductivity slightly more than iron electrode but the amount of decrease is not appreciable. It appears from the plot that the rate of conductivity decrease is slow at high voltages between 6–8V. There is an optimum decrease at around 3–4V, similar trend has been observed by Chen et al. (2) for various types of restaurant wastewaters. For aluminum electrode the turbidity decreases with an increase in voltage (see Fig. 3). But, with the iron electrode the turbidity increases drastically and this may be because of ferric ion formation and slow settling. The decrease in COD is almost the same for both the electrodes (see Fig. 4). In any case, however, the decrease varies from 50 to 72% for different loads; such a decrease in COD was observed for some of the restaurant wastewater samples by Chen et al. (2).

## Effect of Electrolysis Time on Conductivity, Turbidity, COD, and TDS

At a given load the rate of COD removal decreases with time of electrolysis. There is an optimum time for which the rate of decrease in COD is maximum. For the samples under analysis the rate of COD removal is maximum between 15–30 minutes of operation time, as shown in Fig. 5. The change in conductivity

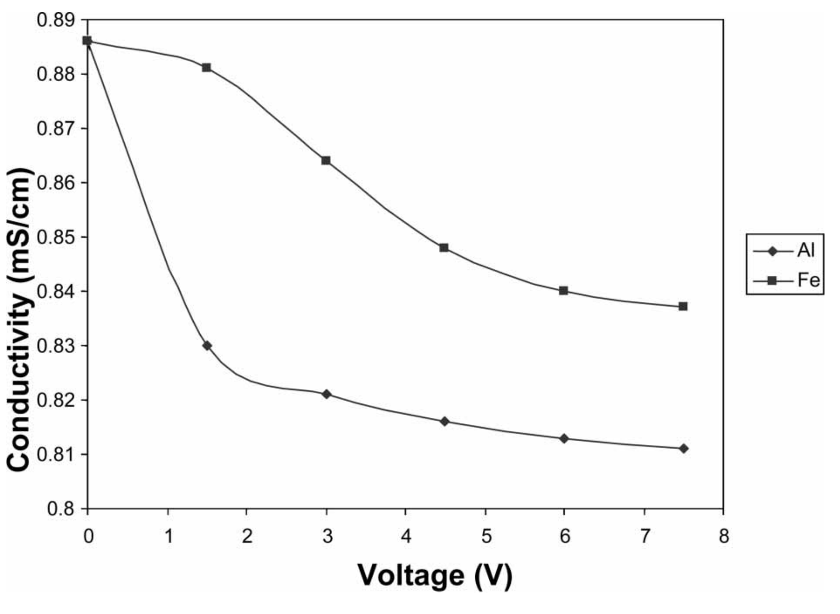


*Figure 2.* Effect of voltage on conductivity of the sample (Electrolysis time: 30 min)

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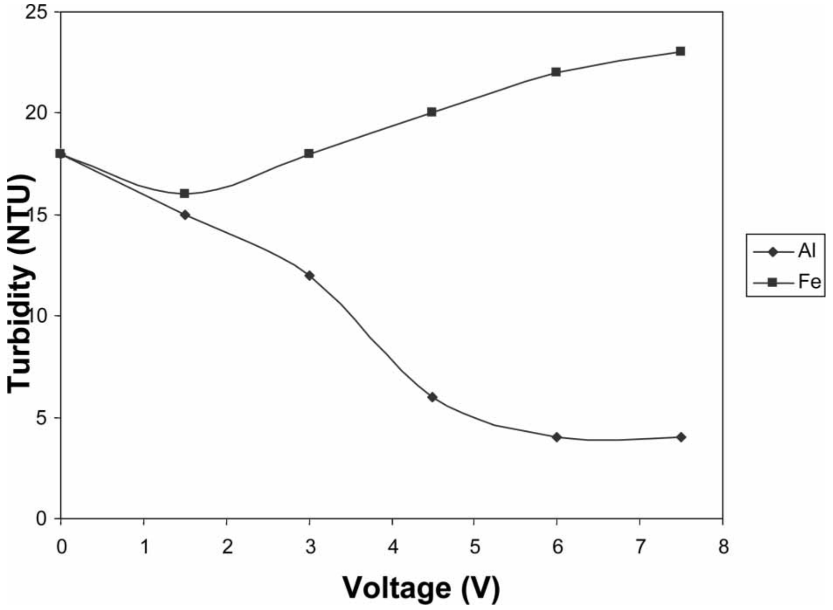


*Figure 3.* Effect of voltage on turbidity of the sample (Electrolysis time: 30 min).

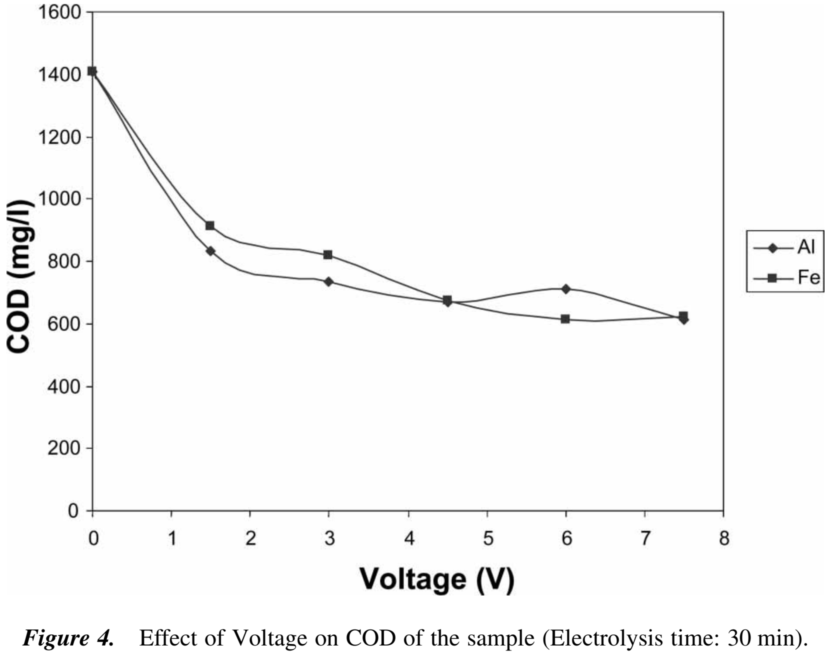


*Figure 4.* Effect of Voltage on COD of the sample (Electrolysis time: 30 min).

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and TDS with time of electrolysis is shown in Fig. 6 and 7, respectively. The rate for both the electrodes is almost the same for both the parameters. Figure 8 shows the turbidity change with time. In case of iron electrode there is a huge change and sample go on getting turbid as time passes, and the trend may be attributed to ferric ion formation, as mentioned earlier.

## Effect of pH on Electrocoagulation

The pH is an important operating factor influencing the performance of EC process (1, 16–18). The pH of the medium changes during the EC process, depending on the type of electrode material and initial pH. EC process exhibits some buffering capacity, especially in alkaline medium, which prevents high changes in pH (1). In the present case the pH variation of the effluents is shown in Fig. 9. It is found that when the influent pH is between 5 to 8, a pH increase is observed in the effluent. But, when the influent pH is $>8$, the effluent pH found to be slightly lesser than that of influent. The change in pH of the effluent solution is attributed to the hydrogen evolution at cathode and/or $CO_2$ transfer, and the detailed reactions are given elsewhere (2, 17). The same trend was observed by Chen et al. (2) for the pH range considered in the present work. It is expected that maximum treatment takes place at around pH 7.

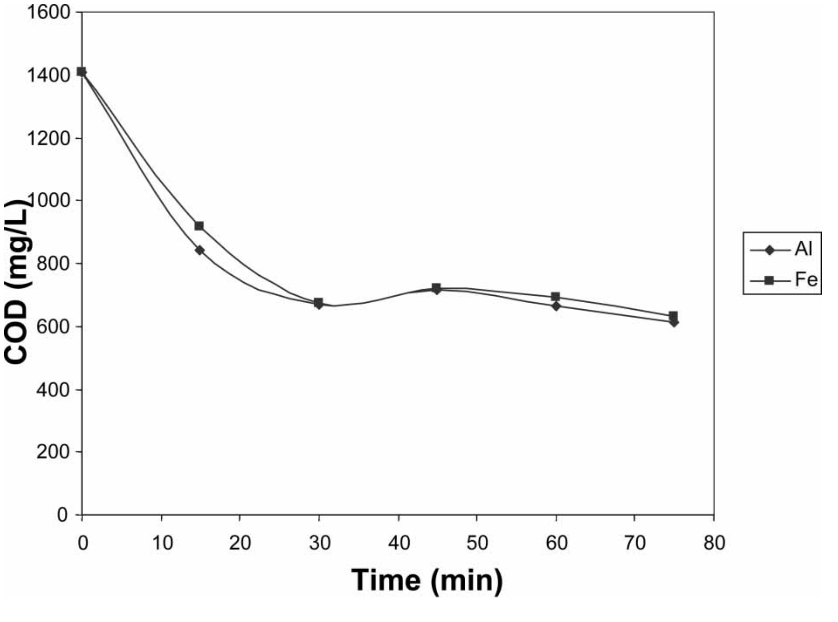


*Figure 5.* Effect of time of electrolysis on COD of the sample (at 4.5 Volts).

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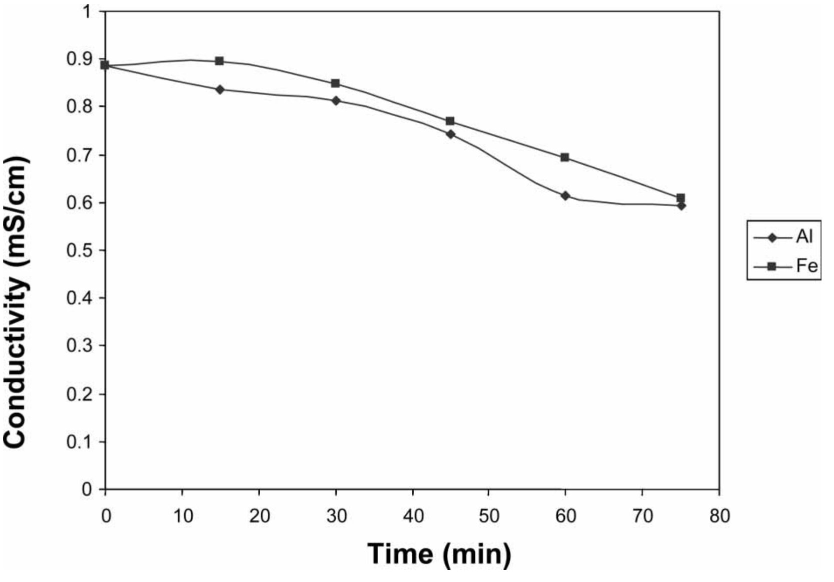


*Figure 6.* Effect of time of electrolysis on conductivity of the sample (at 4.5 Volts).

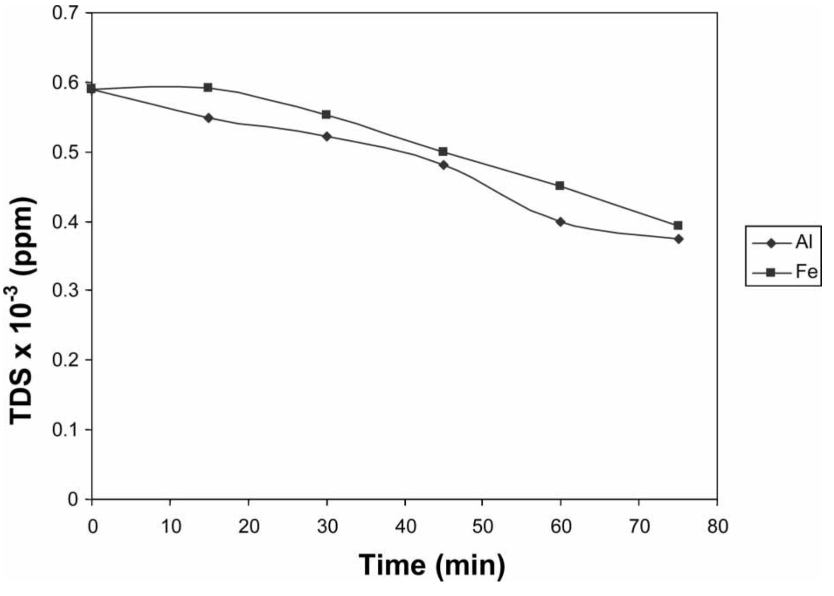


*Figure 7.* Effect of time of electrolysis on TDS of the sample (at 4.5 volts).

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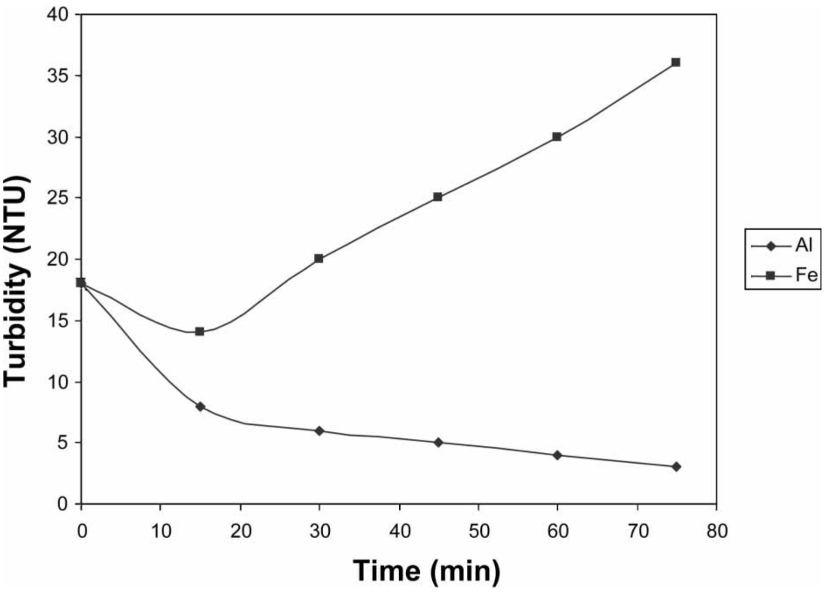


*Figure 8.* Effect of time of electrolysis on turbidity of the sample (at 4.5 volts).

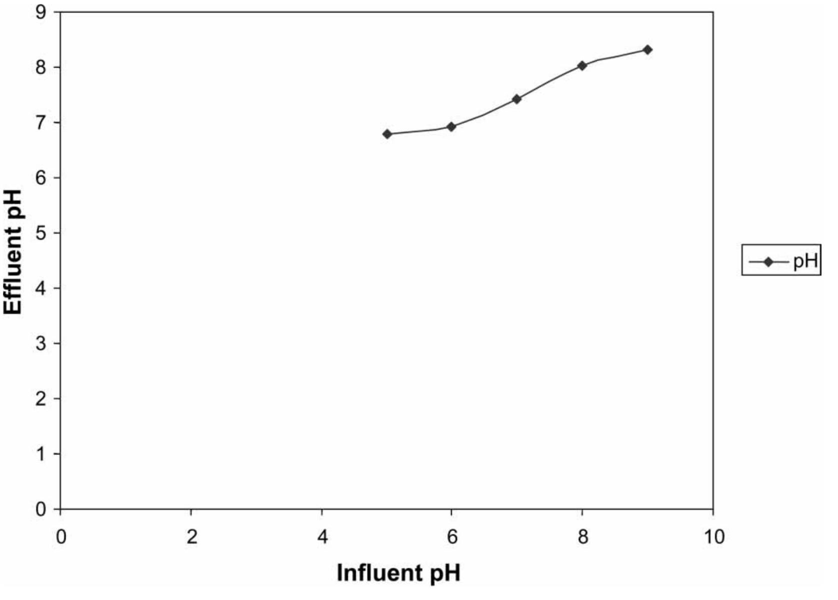


*Figure 9.* pH neutralization effect of electrocoagulation (at 4.5 V and 30 min electrolysis time).

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It is clear from the above analysis that when aluminum is used the effluent is more stable and clear. When iron electrodes are used the effluents turn yellow and turbid on keeping for some time. It is the result of conversion of ferrous ions to ferric ions. Ferric ions on reaction with dissolved oxygen formed ferric hydroxide which is yellow and very difficult to settle (2). The major problems with iron as electrode are corrosion in open circuit. Most of the restaurants are closed at night in India so electrode corrosion will be a major problem in this case. So, if EC method is used to treat restaurant wastewater aluminum happens to be a relatively better electrode than iron.

## Operating Cost Estimation

Electrocoagulation has been found to reduce the turbidity, TDS, COD, etc. There are various cost components that affect the overall cost estimation of the process. The major operating cost components in EC are electrode cost and power cost. Since, the EC operation is done at the laboratory scale, dry sludge disposal cost is not considered in overall cost estimation. The unit cost of electrode materials, aluminum and iron, are considered to be US$ 3.8/kg and US$1.2/kg, respectively. The unit cost of power is taken as US$0.1/kWh. The costs of treating 1000 L (1.0 $m^3$) restaurant wastewater are shown in Figs. 10 and 11 for the cases of aluminum and iron electrodes, respectively. It can be seen from the Figs. 10 and 11 that the operating costs vary linearly in both the cases.

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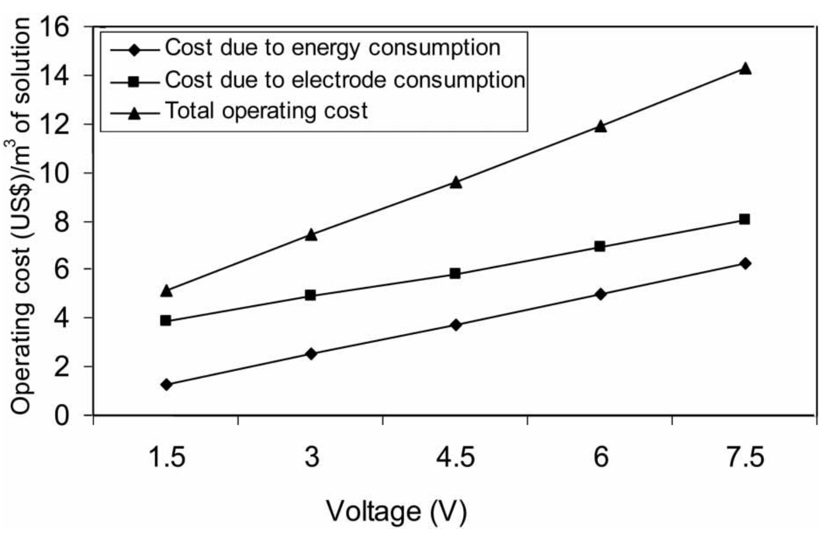


***Figure 10.*** Operating cost estimation of EC process using aluminum electrode.

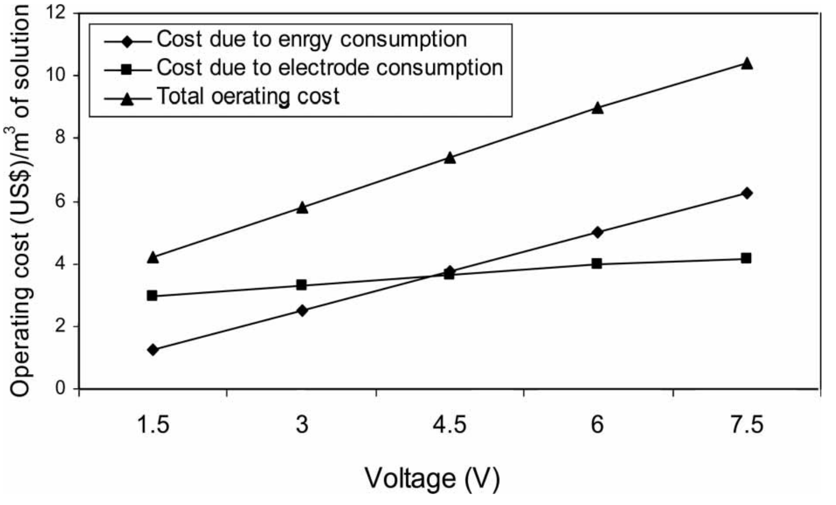


***Figure 11.*** Operating cost estimation of EC process using iron electrode.

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## CONCLUSION

It is found that electrocoagulation is an efficient method for treating restaurant wastewaters. The COD removal efficiency varies from 50–72% in such a process under batch conditions. The effluent from the process that uses iron for electrode assembly is highly turbid. As a result it may not be used to treat restaurant wastewater while aluminum electrodes give very clear and stable effluent. Reduction of TDS with both the electrodes is nearly same. The efficiency of the electrodes is found to be almost the same. Operating cost estimation of the laboratory scale treatment of restaurant wastewater by EC has been done.

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