

Restaurant Wastewater Electrocoagulation and Electroflotation

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ABSTRACT: For the treatment of restaurant wastewater, a combination electrocoagulation and electroflotation procedure was used. Performance effects of operational variables were investigated. The most crucial factors are the charge loadings for electroflotation and electrocoagulation. Initial pH and conductivity have minimal effects on the elimination of pollutants over a wide range. Nevertheless, suspended particles removal dramatically decreases when pH is below 4. Shorter retention time and less water in the produced sludge are two major benefits of the suggested technique. With a set of normal operating conditions, the power requirement is only 0.5 kWh/m³. Chemical oxygen demand removed results in 0.20-0.37 kg/kg of dry sludge.

INTRODUCTION

High oil and grease content is a characteristic of restaurant effluent. About 9,000 restaurants in Hong Kong employ more than 180,000 people. There are also about 200 fast-food restaurants. Every day, this industry uses more than 500,000 tonnes of water. Few wastewater treatment and reuse systems have, however, been put in place in restaurants as of yet. The municipal waste-water treatment facilities bear a heavy burden from the direct discharge of wastewater into the sewer. The compactness of the treatment facility is just as important as the effectiveness of the therapy because most Hong Kong restaurants are cramped. This type of wastewater was treated using electrocoagulation in a prior study (Chen et al. 2000). It was discovered that electrocoagulation works quickly and efficiently to destabilise and aggregate tiny particles. However, only roughly two-thirds of the total flocs could be floated by the hydrogen gas generated at the cathode of the electrocoagulation unit. The suspended solids (SS) in the effluent still need to be further separated because they are still present in substantial amounts.

In this study, restaurant wastewater is treated using a combination electrocoagulation and electroflotation procedure. The electrocoagulation in this process primarily functions to destabilise and aggregate the fine particles, while the electroflotation lifts the flocs that form in the electrocoagulation unit's effluent. Although both electrocoagulation and electroflotation have been widely used in water and wastewater treatment (Dobolyi 1978; Matis 1980; Vik et al. 1984; Demmin and Uhrich 1988; Renk 1988; Murphy et al. 1992; Ogutveren et al. 1992; McClung and Lemley 1994; Matteson et al. 1995; Pouet and Grasmick 1995; Lin and Chen 1997), a combination of electrocoagulation and electroflotation has not been available. The purpose of the current study is to investigate the effects of operational variables on performance as well as the viability of this combination.

EXPERIMENTAL

Fig. 1 depicts the experimental setup schematically. The feeding tank was continuously churned to ensure a constant influent to the treatment system because some pollutants, particularly SS, may settle during an experimental run. Three aluminium electrodes with a combined size of 55 100 3 mm and an effective area of 50 cm² made up the electrocoagulation cell. The aluminium electrodes were spaced 4 mm apart on average. There were two electrodes in the electroflotation cell. Its anode was made of Ti/IrO₂TaO₅, prepared by following the standard thermal decomposition

procedure (Ver-cesi et al. 1991; Mraz and Krysa 1994). The titanium support was first etched in 10% oxalic acid at 55°C for 3 h, then washed with deionized water. A painting solution was created by dissolving the proper proportions of H₂IrCl₆ 6H₂O and TaCl₅ (Ir:Ta = 0.7:0.3) in an ethanol-isopropanol mixture. The prepared titanium support was then covered with 10 successive coats of the painting solution. Each internal layer was annealed at 500°C for 7 minutes after drying at 80°C for 10 minutes. The last layer was dried at 80°C for 10 min and annealed at 500°C for 1 h. The Ti/IrO₂TaO₅ anode had a dimension of 45 × 50 × 1.6 mm and an effective area of 20 cm².

The cathode of the electroflotation cell was a piece of stainless steel mesh and had the same length and width as the anode. There was a fish-scalelike insulating spacer with a thickness of 2 mm located between the anode and the cathode of the electroflotation cell. The electroflotation cell was installed at a 45° angle to the horizontal plane. Wastewater flowed downward in the electrocoagulation cell and upward in the electroflotation cell.

Biological oxygen demand (BOD₅), SS, pH, and conductivity were examined by the standard methods [American Public Health Association (APHA) 1992]. Chemical oxygen demand

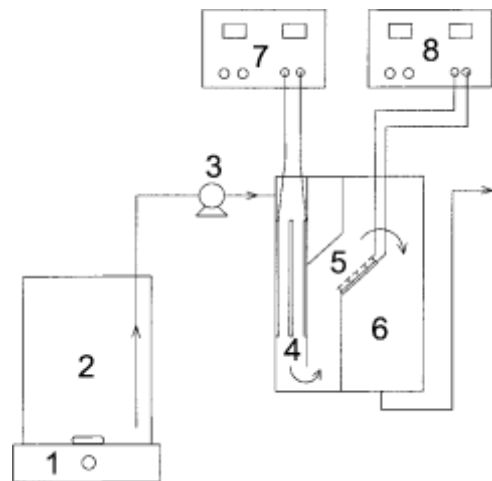


FIG. 1. Schematic Diagram of the Experimental Setup: 1. Magnetic Stirrer; 2. Influent Tank; 3. Pump; 4. Electrocoagulation Cell; 5. Electroflotation Cell; 6. Separator; 7, 8. DC Power Supplies

(COD) was measured using a COD reactor and a direct reading spectrophotometer (DR/2000, Hach Company). Oil and grease were first extracted with petroleum ether at pH <2, then examined using a UV Spectrophotometer (UV-1206 UV-vis spectrophotometer, Shimadzu Corporation, Japan) at 210 nm. Peanut oil was used as the reference standard, because it is the most common food oil in Hong Kong.

RESULTS AND DISCUSSION

Characterization of Restaurant Wastewater

A total of 48 samples were collected from five restaurants in the Hong Kong University of Science and Technology for characterization. Restaurant wastewater is a mixture of wastewater from cleaning meat and vegetables, washing dishes, pans, and other vessels, and rinsing floors. Thus it is expected that the composition of the wastewater from different cuisines would vary significantly. Meanwhile, the food served at a given restaurant depends on the time of service, i.e., breakfast, lunch, or dinner. Hence it is almost impossible to have one set of data to characterize restaurant wastewater. Instead, a range of the values of each parameter is given for each restaurant. The results are presented in Table 1. It can be seen that the oil and grease content is very high, higher in all cases than 100 mg/L, the permitted level for sewer discharge in Hong Kong. The pollutant concentration varies widely, as does the conductivity. The highest COD and oil and grease values were found at the American fast-food restaurant and the Western restaurant, respectively, probably due to the large number of meat dishes on the menus. The highest SS content was found at the student canteen, which provides both Chinese and Western fast food.

Effect of Electrocoagulation Charge Loading

In the electrocoagulation process, the coagulant Al^{3+} is produced by electrochemical sacrifice of the aluminum anode. Its dosage is determined by charge loading. Theoretically, according to Faraday's law, whenever 1 faraday of charge passes through the circuit, 9.0 g of aluminum is dissolved at each anode of a bipolar electrocoagulation unit. Fig. 2 illustrates the effect of the electrocoagulation charge loading on oil and grease, COD, and SS removal under a constant electroflotation charge loading. When electrocoagulation charge loading is zero, only the electroflotation unit is working. In this case, the removal efficiencies of oil and grease, COD, and SS are 67, 40, and 37%, respectively. This indicates that the electroflotation process alone can remove a significant fraction of pollutants from restaurant wastewater. In fact, the effluent from the electroflotation unit has already met the sewer discharge standard for this particular case. However, in most cases, especially when the initial pollutant concentrations are high, electroflotation alone is not sufficient and it must be used together with electrocoagulation.

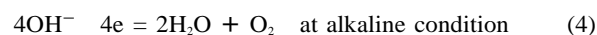
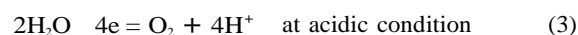
In Fig. 2, a sharp increase in the removal efficiency occurred

initially. After the charge loading was increased to >1.87 faradays/ m^3 , the removal efficiencies approached a plateau of 67% for COD, >97% for oil and grease, and about 90% for SS. The initial rapid removal of pollutants is attributed to the electrocoagulation of colloidal and finely suspended particles. When the charge loading of the electrocoagulation was low, the Al^{3+} dosage was not sufficient to destabilize all colloidal and finely suspended particles, and thus the COD removal efficiency was not high. After the colloidal and finely suspended particles were removed, a further decrease of COD resulted from adsorption and electrochemical oxidation of soluble organic components. Usually, freshly formed aluminum hydroxide floc has a large specific surface area that can adsorb some soluble organic compounds onto its surface. Although the main reaction at an aluminum anode in an electrocoagulation process is the sacrifice of the electrode to form aluminum ion, there are also other secondary reactions as shown below.

Main reaction:



Secondary reactions:



The chlorine produced from (2) is a strong oxidant that can oxidize some organic compounds present in wastewater. Moreover, if the potential applied to the anode is sufficiently high, direct oxidation of organic compounds is also possible as in-

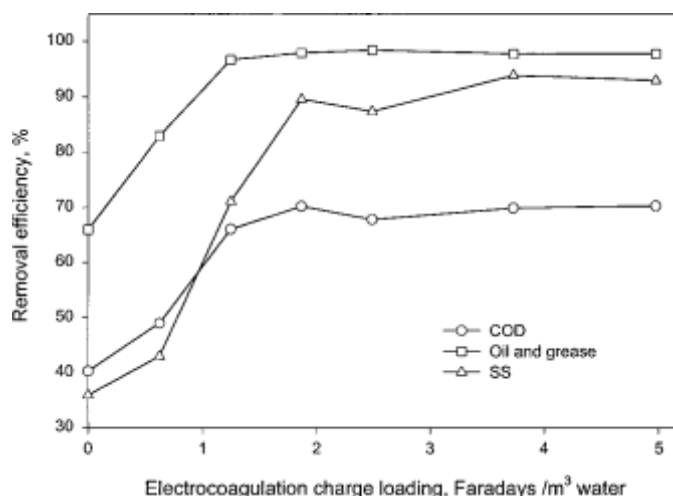


FIG. 2. Effect of Electrocoagulation Charge Loading: Initial COD = 1,520 mg/L, Oil and Grease = 250 mg/L, SS = 228 mg/L, Conductivity = 1,290 μ S/cm, pH = 6.94, Temperature = 30.4°C, Total Retention Time = 15 min, Electroflotation Charge Loading = 0.93 Faradays/ m^3 Water

TABLE 1. Characteristics of Restaurant Wastewaters^a

Parameters (1)	Chinese restaurant (2)	Western restaurant (3)	American fast food (4)	Student canteen (5)	UC bistro (6)	Permission standards (7)
Number of samples	10	10	11	14	3	—
pH	6.62–7.96	6.94–9.47	6.30–7.23	6.82–8.76	6.03–8.22	6–10
COD, mg/L	292–3,390	912–3,500	980–4,240	900–3,250	1,500–1,760	3,000
BOD ₅ , mg/L	58–1,430	489–1,410	405–2,240	545–1,630	451–704	1,200
Oil and grease, mg/L	120–712	52.6–2,100	158–799	415–1,970	140–410	100
SS, mg/L	13.2–246	152–545	68–345	124–1,320	359–567	1,200
Conductivity, μ S/cm	227–661	261–452	254–706	233–1,570	341–514	—

^aAfter Chen et al. 2000.

indicated by (5), where R and R' represent the original organic compound and the reaction product, respectively.

$$R \rightarrow R' \quad (5)$$

Gas chromatography/mass spectrometer analyses of both the original wastewater and the effluent showed that there were some new components in the effluent. This indicates that electrochemical oxidation really occurs during the combined electrocoagulation and electroflotation process, because pure physical processes such as coagulation and adsorption cannot break a chemical compound or change its molecular structure.

Effect of Electroflotation Charge Loading

The effect of electroflotation is to further remove the particles that have aggregated but not separated out during the electrocoagulation process. Because the electroflotation charge loading determines the amount of gas produced in this process directly, it is an important operational variable. Fig. 3 shows the effect of the electroflotation charge loading on oil and grease, COD, and SS removal. It can be seen from the figure that the oil and grease removal efficiency was >96% at zero electroflotation charge loading. This indicates that the separation of the oil and grease was almost complete after electrocoagulation. However, the increase in SS and COD removal due to electroflotation is significant. As the charge loading increased from zero to 0.50 faradays/m³, the removal efficiencies increased rapidly from 65 to >90% for SS and from 62 to 71% for COD.

It should be noted that electroflotation also accompanies the electrocoagulation process due to the generation of hydrogen bubbles at the cathode. Theoretical calculation shows that the amount of gas produced in that process is 0.041 N·m³/m³ wastewater at a charge loading of 1.85 faradays/m³. This is greater than the volume of gas released in the conventional flotation process. However, the SS separation efficiency is still low. One reason is that electrocoagulation cannot produce uniform tiny bubbles. It is generally believed that the smaller the bubbles, the better the separation efficiency of a flotation process. This is because smaller bubbles provide larger surface areas for particle attachment. Although bubble size distribution was not measured in the present study, it was observed that most of the hydrogen bubbles produced in the electrocoagulation unit were >100 μm, because they could be discerned easily. It is useful to point out that the bubbles generated by

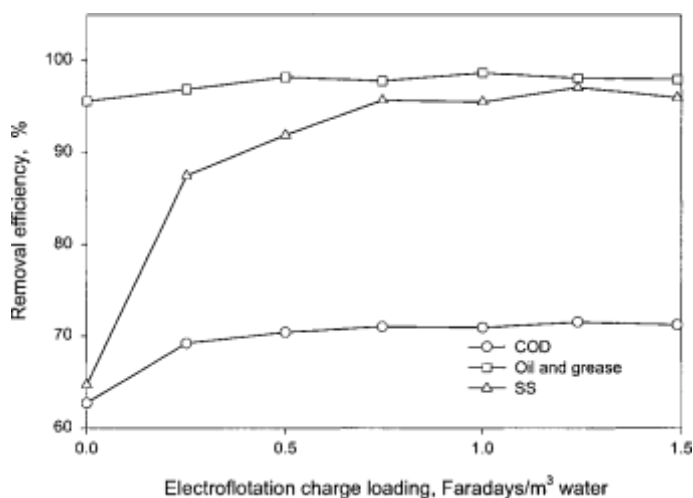


FIG. 3. Effect of Electroflotation Charge Loading: Initial COD = 1,520 mg/L, Oil and Grease = 250 mg/L, SS = 228 mg/L, Conductivity = 1,290 μS/cm, pH = 6.94, Temperature = 30.4°C, Total Retention Time = 15 min, Electrocoagulation Charge Loading = 2.49 Faradays/m³ Water

the release of pressure from air-saturated water have a size of about 50–70 μm (Stevenson 1997).

Another reason for the poor SS separation of electrocoagulation is that the bubbles produced at cathodes could not mix with wastewater quickly. It was found that most bubbles tended to rise along a cathode surface and to merge with each other rapidly. This decreases the chance of effective contact between bubble and particles. As a result, the SS separation efficiency was reduced during electrocoagulation. This explains the low SS separation efficiency of electrocoagulation. In addition, large bubbles disturb wastewater flow strongly while they are rising. It is well known that proper disturbance can improve flocculation because it increases the chances of collisions between small particles. However, excessive disturbance is not beneficial to flocculation because some large flocs may be easily broken.

The production of large bubbles in electrocoagulation is associated with the surface structure of the aluminum electrode. The aluminum electrode surface is usually rough because of numerous electrochemical corrosion pits, especially when electrode polarity needs to change periodically for the purpose of decreasing passivation. The rough electrode surface can provide larger adhering forces to bubbles than a smooth electrode surface. This makes it more difficult for electrocoagulation to generate small bubbles. Therefore, to obtain small bubbles, it is very important to keep the electrode surface smooth. However, for electrocoagulation, formation of a rough surface is inevitable due to dissolution of the electrode.

To improve the performance of an electrochemical unit, the electrodes can be installed at an angle to the horizontal plane so that the mixing of bubbles within wastewater is enhanced. The drawback of this arrangement is that the electrodes may be bent after usage for a certain amount of time due to electrochemical dissolution. Consequently, a short circuit may happen because of contact of electrodes. Therefore, slanted installation of electrodes in an electrocoagulation unit is not practical. However, the situation in electroflotation is quite different because the electrodes are inert. Using a smooth activated titanium anode and a stainless steel mesh cathode, large amounts of tiny bubbles can be produced. Their sizes are so small that they cannot be easily seen using the naked eye. Actually, typical bubble sizes in electroflotation are only 20 – 70 μm (Murphy et al. 1992), smaller than those produced in conventional flotation. In addition, slant installation of electrodes guarantees that the tiny bubbles produced will mix with wastewater effectively. Thus, electroflotation has a higher SS separation efficiency even at low charge loadings.

Effect of Retention Time

Electrocoagulation involves two stages, destabilization and aggregation. The first stage is usually short, whereas the second stage is relatively long. Electroflotation is a physical process in which suspended pollutants are separated from wastewater. Only when the rising velocity of a particle is larger than the downward velocity of wastewater flow can the particle be separated out from the wastewater. The investigation of the effect of retention time on treatment efficiency was conducted under a fixed charge loading, which was achieved by altering the wastewater flow rate in proportion to the applied current. The result is shown in Fig. 4. It appears that retention time has no significant effect on the pollutant removal efficiency within the investigation range. Even when the retention time was as short as 4.3 min, the removal efficiencies of oil and grease, COD, and SS were still 99, 88, and 98%, respectively.

Effect of Influent pH

Previous work (Chen et al. 2000) showed that over a large range influent pH did not affect the pollutant removal effi-

ciency significantly in an independent electrocoagulation process. To examine the effect of influent pH on the combined electrocoagulation and electroflotation process, the wastewater was adjusted to the desired pH for each experiment, using sodium hydroxide or sulfuric acid. The result is shown in Fig. 5. Similar to an independent electrocoagulation process, the influent pH did not affect the removal efficiencies significantly over a wide range. Specifically, oil and grease removal was >98% throughout the investigated pH range of 2.6 – 10. The SS removal deteriorates only when pH is <4. Similarly, a slight drop in COD removal was observed only at pHs >9 or <3. Because restaurant wastewaters have pH values between 6.0 and 8.7 (Table 1), pH adjustment before treatment is not required in practical applications.

The maintenance of a high removal efficiency in a wide range of pHs can be understood. The mechanism of destabilization of the dispersed particles during electrocoagulation using aluminum electrodes is similar to that of chemical coagulation using alum as a coagulant. Both processes rely mainly on various aluminum intermediate products formed during hydrolysis of Al^{3+} . It has been found that effective coagulation

is achieved at pHs of 6 – 7 for chemical coagulation (Sanks 1978). It is obvious that electrocoagulation can work effectively over a much wider pH range, as shown in Fig. 5. This finding is attributed to one of the characteristics of electrocoagulation—the ability to neutralize wastewater pH. That is, when influent pH is acidic, effluent pH value rises, and when influent pH is alkaline, effluent pH drops (Chen et al. 2000). Thus, the pH value in the effluent will be brought closer to neutral, where effective coagulation has been reported. Modest decrease of COD removal at pH <4 or >9 was probably due to less $Al(OH)_3(s)$ formation in this pH range. As discussed above, $Al(OH)_3$ can remove part of the soluble COD contents by adsorption. Therefore, less production of $Al(OH)_3$ results in lower COD removal efficiency.

Effect of Conductivity

Generally, restaurant wastewater contains more NaCl than wastewaters found from other industries. Due to the nature of the food service industry, the NaCl concentration in wastewater changes from time to time. Therefore, it is necessary to investigate the effect of wastewater conductivity on the performance of combined electrocoagulation and electroflotation. Although salinity can be determined easily, its relation to the electroprocesses is not as obvious as conductivity. Because direct measurement of NaCl concentration was not convenient, electrical conductivity was selected as a variable to investigate instead. To illustrate the relationship between electrical conductivity and NaCl concentration, a change of 1 ppm of NaCl causes a change of about 2 $\mu S/cm$ in conductivity at low concentrations of NaCl.

To isolate the effect of changes in conductivity under a common set of conditions, the same lot of wastewater was used in the experiments of this section. However, the conductivity of the samples from the wastewater was adjusted to the desired levels by adding an appropriate amount of NaCl. It appears that pollutant removal efficiency was not significantly affected by the wastewater conductivity over the range investigated, as shown in Fig. 6. One explanation for such an observation is that destabilization of dispersed particles is primarily accomplished through the mechanism of adsorption and charge neutralization of electrochemically produced Al^{3+} and its hydrolysis products, whereas the contribution from Na^+ through double-layer compression is insignificant. Another explanation is that indirect electrochemical oxidation of soluble organic

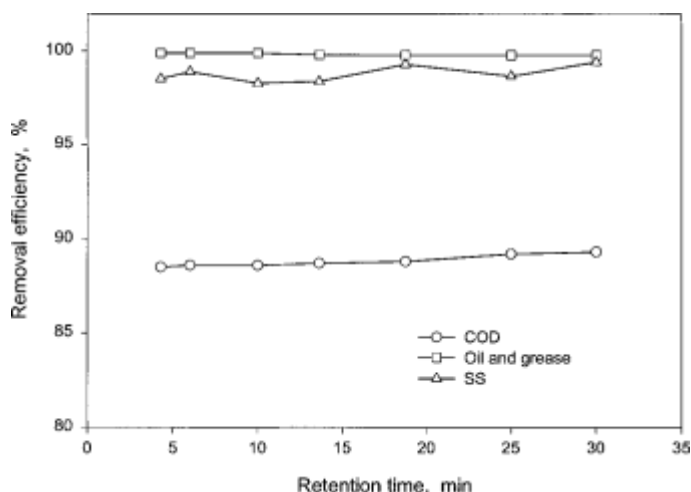


FIG. 4. Effect of Retention Time: Initial COD = 3,770 mg/L, Oil and Grease = 650 mg/L, SS = 800 mg/L, Conductivity = 790 $\mu S/cm$, pH = 7.37, Temperature = 28.1°C, Electrocoagulation Charge Loading = 6.22 Faradays/ m^3 Water, Electroflotation Charge Loading = 3.11 Faradays/ m^3 Water

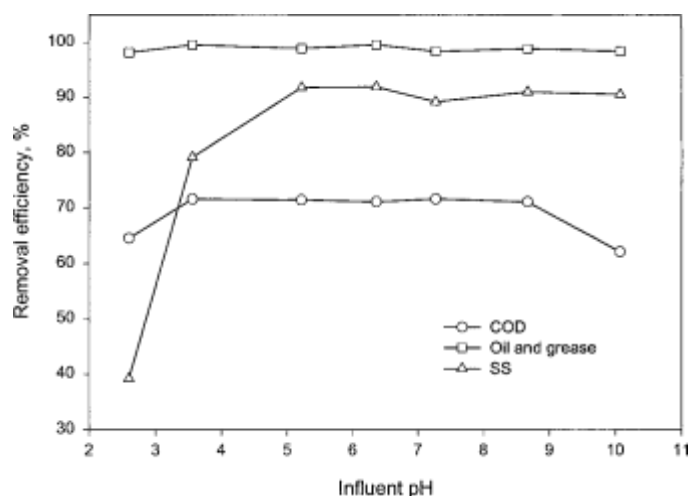


FIG. 5. Effect of Influent pH: Initial COD = 920 mg/L, Oil and Grease = 200 mg/L, SS = 208 mg/L, Temperature = 24.6°C, Total Retention Time = 15 min, Electrocoagulation Charge Loading = 3.73 Faradays/ m^3 Water, Electroflotation Charge Loading = 1.87 Faradays/ m^3 Water

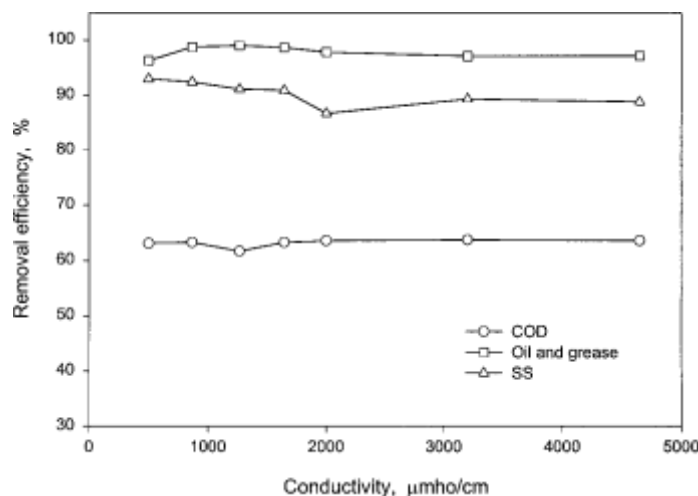


FIG. 6. Effect of Conductivity: Initial COD = 632 mg/L, Oil and Grease = 92 mg/L, SS = 233 mg/L, pH = 6.86, Temperature = 24.6°C, Total Retention Time = 15 min, Electrocoagulation Charge Loading = 3.11 Faradays/ m^3 Water, Electroflotation Charge Loading = 1.55 Faradays/ m^3 Water

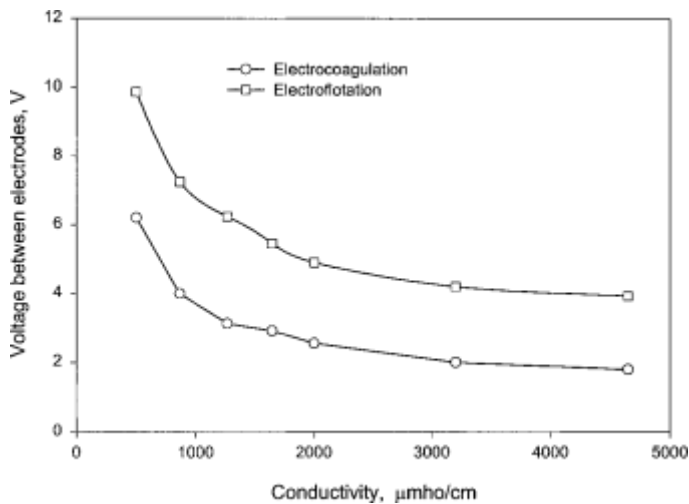


FIG. 7. Effect of Conductivity on Electrolysis Voltage: Current Density of Electrocoagulation = 50 A/m², Current Density of Electroflotation = 125 A/m², Temperature = 25.4°C, Total Retention Time = 15 min, Electrocoagulation Charge Loading = 3.11 Faradays/m³ Water, Electroflotation Charge Loading = 1.55 Faradays/m³ Water

compounds by chlorine at anodes is not significant either due to the low concentrations of NaCl (about 250 and 2,500 ppm at conductivities of 498 and 4,650 µS/cm, respectively). Thus COD removal is maintained at the same level.

The conductivity can strongly affect the electrolysis voltage, as shown in Fig. 7. As the conductivity increased from 498 to 4,650 µS/cm, the applied voltage between electrodes decreased from 6.2 to 1.8 V for the electrocoagulation cell and from 9.9 to 3.9 V for the electroflotation cell. As it has been established that charge loadings are the primary factors affecting pollutant removal, it is important to have a constant current for a given flow rate of wastewater. If a constant voltage DC power source is employed, charge loading will vary with the conductivity of the wastewater treated, which is not desirable. Therefore, a DC power supply with a constant current output function should be employed for the technique proposed here.

Sludge Production

When wastewater passes through the electrocoagulation-electroflotation system, most pollutants are separated from and floated on the surface of the wastewater in the form of sludge. It was observed that about two-thirds of the sludge was produced in the electrocoagulation cell and the other one-third in the electroflotation separation tank (Table 2). The amounts of wet sludge and dried sludge were 4.04 – 9.64 and 0.29 – 0.48 kg/m³ wastewater, respectively. The amount of sludge produced is related to the amount of pollutants removed. Removing 1 kg COD produces about 0.20–0.37 kg of dried sludge.

Comparison of Electrocoagulation-Electroflotation and Electrocoagulation-Sedimentation

Table 3 presents a comparison between the electrocoagulation-electroflotation and electrocoagulation-sedimentation in terms of the treatment efficiency and the water content of the sludge produced. The total retention time for the electrocoagulation-electroflotation was 15 min and that for the electrocoagulation-sedimentation was 2 h. The sedimentation experiment was conducted in a batch operation. It is clear that although the retention time for the electrocoagulation-electroflotation process was only one-eighth that of the electrocoagulation-sedimentation process, the two processes had a similar

TABLE 2. Sludge Formation in Combined Electrocoagulation and Electroflotation

COD removed (kg/m ³) (1)	Dried sludge (kg/m ³) (2)	Dried sludge/COD removed (kg/kg) (3)
0.84	0.29	0.35
1.42	0.29	0.20
1.09	0.40	0.37
1.58	0.48	0.30

TABLE 3. Comparison of Electrocoagulation with Electroflotation and Electrocoagulation with Sedimentation

Process (1)	Removal efficiency (%)		Water content (%)	
	COD (2)	Oil and grease (3)	SS (4)	Sludge (5)
Electrocoagulation-electroflotation	60.7	98.3	86.4	92.2
Electrocoagulation-sedimentation	61.1	98.5	96.4	99.3

Note: Initial COD = 1,370 mg/L, oil and grease = 325 mg/L, SS = 225 mg/L, pH = 6.75, electrocoagulation charge loading = 2.49 faradays/m³ water, electroflotation charge loading = 1.24 faradays/m³ water, feed flow rate = 6 L/h.

removal efficiency for COD and oil and grease. However, the SS removal efficiency of electrocoagulation-sedimentation was higher because of the long settling time. The water content of the sludge produced from electrocoagulation-electroflotation was much lower than that from the electrocoagulation-sedimentation.

Energy Consumption

The total energy consumption during electrocoagulation and electroflotation can be calculated according to

$$E = [(n - 1)U_{ec}I_{ec} + U_{ef}I_{ef}]/(1,000Q) \quad (6)$$

where E = energy consumption (kW·h/m³ wastewater); n = aluminum plate numbers in a bipolar electrocoagulation cell; U_{ec} = electrolysis voltage between electrodes of electrocoagulation (V); I_{ec} = electrolysis current of electrocoagulation (A); U_{ef} = electrolysis voltage between electrodes of electroflotation (V); I_{ef} = electrolysis current of electroflotation (A); and Q = wastewater flow rate (m³/h). Eq. (6) can be rearranged

$$E = \frac{96,500}{1,000 \times 3,600} \left[\frac{3,600(n - 1)U_{ec}I_{ec}}{96,500Q} + \frac{3,600U_{ef}I_{ef}}{96,500Q} \right]$$

or

$$E = 0.0268(U_{ec}q_{ec} + U_{ef}q_{ef}) \quad (7)$$

where

$$q_{ec} = \frac{3,600(n - 1)I}{96,500Q}$$

electrocoagulation charge loading (faradays/m³ water)

$$q = \frac{3,600I_{ef}}{96,500Q}$$

electroflotation charge loading (faradays/m³ water).

Eq. (7) shows that energy consumption during electrocoagulation and electroflotation is related to electrolysis voltages and charge loadings. The larger the applied voltages and the charge loadings, the higher the energy consumption. Both elec-

trocoagulation and electroflotation required charge loadings depend on the influent wastewater property and effluent water quality.

Because the components of restaurant wastewater are very complex and different restaurant wastewaters have different properties, electrocoagulation and electroflotation charge loadings can only be determined by experiment.

The electrolysis voltage between two electrodes is the summation of the equilibrium potential difference, anode overpotential, cathode overpotential, and ohmic potential drop of the solution resistance as shown below (Scott 1995)

$$U_{ec} = (E_{eq_{ec}}) + (h_{a_{ec}}) + |(h_{c_{ec}})| + \frac{d_{ec}}{\kappa} j_{ec} \quad (8)$$

$$U_{ef} = (E_{eq_{ef}}) + (h_{a_{ef}}) + |(h_{c_{ef}})| + \frac{d_{ef}}{\kappa} j_{ef} \quad (9)$$

where E_{eq} = equilibrium potential difference between the anode and the cathode (V); h_a = anode overpotential (V); h_c = cathode overpotential (V); d = distance between anode and cathode (m); κ = conductivity (S/m); j = current density (A/m²); and subscripts ec and ef represent electrocoagulation and electroflotation, respectively.

Under the typical operating conditions with charge loadings of 1.87 faradays/m³ for the electrocoagulation cell and 0.50 faradays/m³ for the electroflotation cell, a current density of 80 A/m² for both cells, and a wastewater conductivity of 700 μ S/cm, the measured electrolysis voltages between electrodes were 8.0 V for electrocoagulation and 7.0 V for electroflotation. Therefore, the total electrolysis energy consumption

$$E = 0.0268(U_{ec}q_{ec} + U_{ef}q_{ef}) = 0.0268(8.0 \cdot 1.87 + 7.0 \cdot 0.50) \\ = 0.5 \text{ kW} \cdot \text{h/m}^3 \text{ wastewater}$$

CONCLUSIONS

The combined electrocoagulation and electroflotation is a feasible process for the treatment of restaurant wastewater. The influent pH and conductivity do not affect the pollutant removal efficiency significantly, although a sharp decrease of SS removal was observed at pH < 4. The electrocoagulation charge loading and the electroflotation charge loading are the most important operational variables for treatment efficiency. The combined electrocoagulation and electroflotation process has two significant advantages, shorter retention time and dried sludge produced. The removal efficiencies of oil and grease, COD, and SS are high, being 99, 88, and 98%, respectively, with retention time being <4.5 min. The amount of dried sludge is 0.20 – 0.37 kg/(kg COD removed). The total electrolysis energy consumption is 0.5 kW·h/(m³ wastewater) under typical operating conditions.

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