

Electrocoagulation of phenol for wastewater treatment

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Abstract

Electrocoagulation is an electrochemical process of treating polluted water where sacrificial anode corrodes to produce active coagulant (usually aluminum or iron cations) into solution. Accompanying electrolytic reactions evolve gas (usually as hydrogen bubbles). The present study investigates the removal of phenol from water by this method. A glass tank with 1 liter volume and two electrodes were used to perform the experiments. The electrode connected to a D.C. power supply. The effect of various factors on the removal of phenol (initial phenol concentration, electrode size, electrodes gap, current density, pH and treatment time) were studied. The results indicated that the removal efficiency decreased as initial phenol concentration increased, the highest removal obtained at pH in the range (6-8), the removal enhanced with increasing electrode size and decreasing the gap between the electrodes. The optimum current density obtained at 221 A/m².

Key words: Electrocoagulation, Flotation, Phenol, Wastewater

Introduction With the development of industry, more and more pollutants are discharged into environment, among them, phenolic wastes are typical contaminants considered to be hazardous and top priority toxic pollutants listed by the USEPA.

They are toxic even at low concentration, the treatment of these contaminants is very important in environmental protection.[1]. Various technologies and processes have been tried for treating phenol contaminants, Electrocoagulation is an advanced method for the treatment of phenol. Electrochemistry, coagulation and flotation are identified as the key foundation sciences for electrocoagulation.

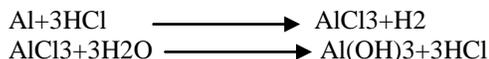
Electrocoagulation uses an electrochemical cell to treat polluted water a sacrificial metal anode (usually aluminum but sometimes iron) is used to dose polluted water with a coagulant agent. Electrolytic gases are generated (typically hydrogen at cathode [2,3]. The coagulant's delivery and its nature influenced the coagulation and separation process by its speciation, removal path and associated by-product electrolytic gases [4].

Electrocoagulation has the capability to remove a wide range of pollutants including suspended solids, heavy metals, dyes, organic material. FOG's (i.e, fats, oils and

greases), ions and radionuclides [5,6,7]. Electrocoagulation has been compared to chemical coagulation to assess its efficiency and advantages. Chemical dosing delivers the coagulants as a salt that dissociates in the solution with hydrolysis of the aluminum action determining solution speciation and pH. Alum (i.e aluminum sulphate) addition acidifies the water. By contrast, aluminum added via electrocoagulation does not bring with any associated salt anions, with the result that the pH typically stabilizes in the alkaline range [8].

The aluminium cation has a variety of paths available (depending upon the treatment properties, solution pH and concentration), it could directly interact with the pollutants, it could hydrolyse to form a hydro-aluminium complex, or it could precipitate [9]. The active metal cation (produced at the anode) reacts with hydroxide ions (produced at the cathode) to form a metal hydroxide which then acts as a coagulant, with the pollutant particles and metal hydroxides forming larger aggregates which may either settle out or be carried to the surface by hydrogen bubbles produced at the cathode [11]. The equilibrium for the aluminum water system occurs as a result of passivation (i.e. formation of an oxide layer) and corrosion is identified. The presence of the chloride

ion in solution has been reported to decrease passivation and thereby increase Electrocoagulation pollutant removal efficiency [10,11]. The mechanism for chloride ion reducing passivation of the oxide layer formed on aluminum as shown in equations below [2].



The Electrocoagulation process is characterized by a fast rate of pollutant removal, compact size of the equipment, simplicity in operation and low operating and equipment costs [12].

The electrolytic bubbles are typically small (less than 50 μm in diameter) close to neutral buoyancy, and present in low concentration. For a given gas volume a smaller bubble diameter results in both a greater surface area and more bubbles, thereby increasing the probability of collision and the ability to remove fine pollutant particles [13].

Materials and Methods

The polluted water was prepared using phenol provided by (Sdfine-Chem. Limited India).

Hydrochloric acid and sodium hydroxide were used as pH modifiers and the control was affected by means of digital pH meter. 4 grams of sodium chloride were added to the solution to increase the conductivity of the solution and to prevent the formation of the oxide layer on the anode and therefore reduced the passivation problem of the electrodes [10].

Experimental Apparatus:

Electrochemical removal of phenol from water was carried out in the electrochemical cell shown in figure (1) the internal size of the reactor (10*10*12 cm) (width*length*depth) with an effective volume of 1 liter. Two electrodes were used, the first one Aluminum electrode as anode and the other one iron as cathode. Power supply having an input of 220 V and variable output of (0-30 V) with a maximum current of 3 amper was used as a direct current source. Samples were taken every 20 minutes and analyzed for phenol concentration by using UV-160 apparatus at 270 nm. The equation used to calculate the phenol percent recovery in the treatment experiment was:

$$R\% = \frac{C_0 - C}{C_0} * 100$$

Where: C_0 =initial phenol concentration.
 C =present phenol concentration.
 R =Recovery.

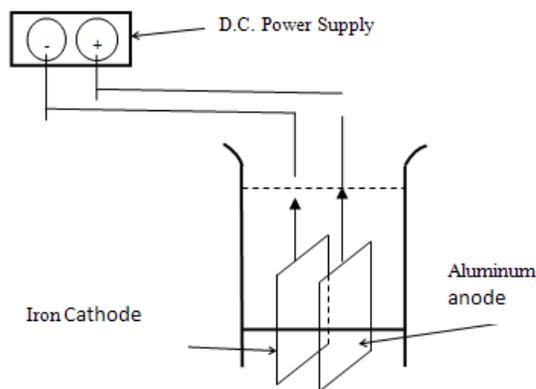
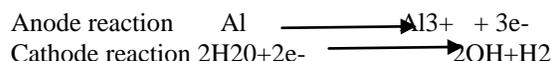


Fig.1: Electrocoagulation Apparatus

RESULTS AND DISCUSSION

As pointed previously that the main reaction occurring during the electrolysis in the electrochemical cell produced aluminum ion at the cathode and hydroxide ion as well as hydrogen at the cathode as shown below:



The aluminum ion that resulted from anode reaction reacts with hydroxyl ion to form gelatinous aluminum hydroxide $\text{Al}(\text{OH})_3$ thus effects the coagulation of phenol from the solution by adsorption. Also the aluminum ion liberated from the anode may interact directly with phenol which then precipitates out of the solution in the form of an insoluble salt ,e.g. aluminumtriphenolate $[\text{Al}(\text{OAr})_3]$ [14].

In Electrocoagulation the electrodes of the electrochemical cell are connected to an electrical power source, the relationship between current density (A/cm^2) and the amount of aluminum which goes into solution (g Al cm^{-2}) can be calculated by using faraday's law[9]:

$$w = \frac{i t M}{z F}$$

Where: w =aluminum dissolving (g Al cm^{-2}).

i =current density (A/cm^2).

t = time (s).

M = molecular weight of Al ($m=27$).

Z =number of electrodes involved in the oxidation reduction reaction ($z=3$)

F = Faraday's constant (96500).

During the experiments, the Al-electrode was weighted. The theoretically calculated amount of Al dissolved compared with the weighted values of Al dissolved is plotted in fig.(2), the correlation found was ($R^2=0.97$) and in the further experiments the Al-dissolved was calculated based on Faraday's law.

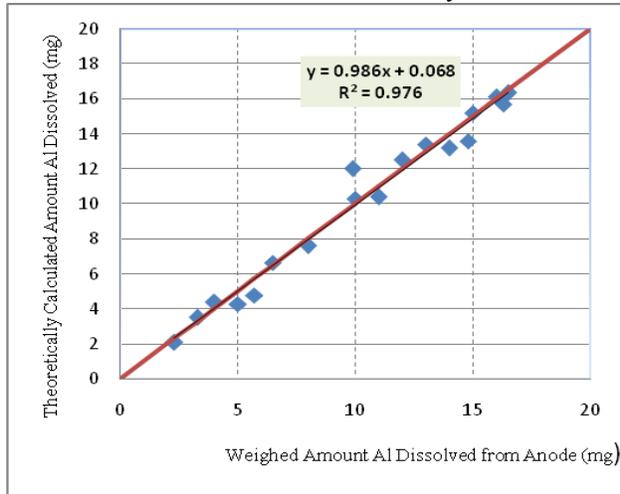


Fig.2: Calculated vs. weighted amount of Al dissolved

The influence of current density on the percent recovery of phenol from water is carried out at 40 °C. In addition the initial phenol concentration is 50 ppm and Aluminum and iron electrode sizes of (10*5*0.05 cm) were used. As shown in figure (3) it can be seen that an increase in the percent recovery from (33 to 88 %) yields with an increase in current density from (49.3 to 246 A/m²) and this is due to that with an increase in the current density, the ion production on both anode and cathode increased resulting in an increase in the floc production in the solution. In addition bubble density increases and their sizes decrease resulting in both greater upward momentum flux and increasing mixing. So that the optimum current density for a solution with phenol concentration of 50 ppm was 221 A/m².

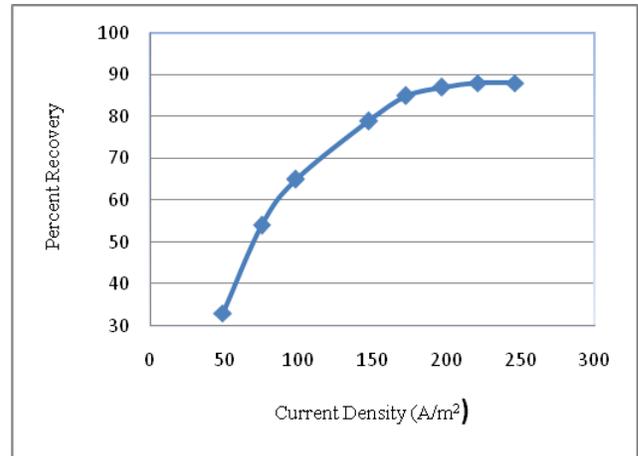


Fig.3: Effect of Current Density on the phenol percent recovery (pH=6, 40 °C, 50 ppm)

Three different sizes of electrodes (10x5, 10x3, 10x2) cm² is used to investigate the effect of the electrode size on the percent recovery. The result is shown in figure (4), from this figure it can be seen that the electrode size of (10x5x0.05cm) had a better percent recovery than the other two smaller sizes, the explanation of this phenomena as follows: larger electrode surface area resulted in a greater dispersion of bubbles throughout the reactor, whereas a smaller electrode surface resulted in a concentrated source of bubbles within the reactor, and with increasing the dispersion of bubbles in the reactor probability of collision between the bubbles and coagulant increased leading to increase the percent recovery.

The effect of electrodes spacing (2.0, 2.5 and 3.0 cm) is plotted in figure (5) and it can be concluded from this figure that the efficiency increased with decreased the gap between the electrodes.

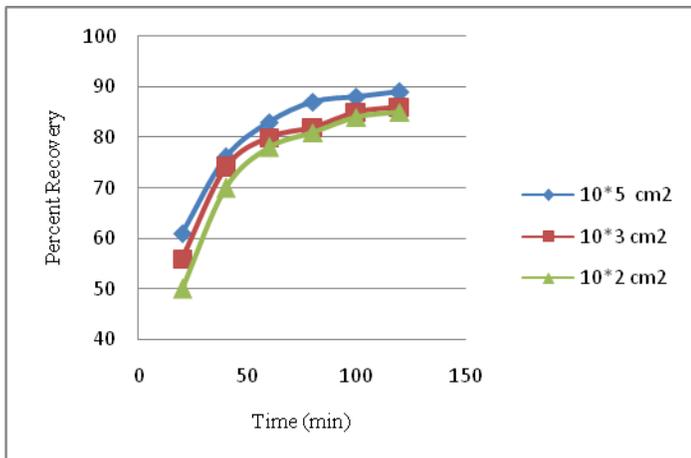


Fig.4: Effect of electrode size on phenol removal efficiency (pH=6, 40 °C, 50 ppm, 221 A/m²)

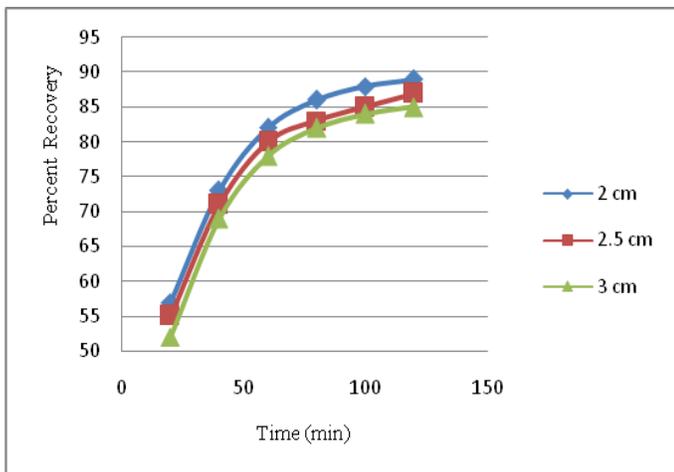


Fig.5: Effect of electrode spacing on phenol removal efficiency (pH=6, 40 °C, 50 ppm, 221 A/m²)

The effect of initial phenol concentration (50,100,150,200 ppm) on the percent recovery is shown in figure (6). It can be seen that at high phenol concentration (200 ppm) the removal rate was very fast at first (20 minutes) and then became very slow later, with increasing phenol concentration the removal efficiency decreased because at the same condition the flocs and hydrogen production is constant value resulted in a decrease in the adsorption capacity and

flotation rate. Up to the first (120 min) the adsorption capacity of flocs was not exhausted and with progressive of the reaction time desorption to the solution took place resulted in decrease of phenol removal efficiency especially at the higher concentration.

pH has a considerable effect on the efficiency of the electrocoagulation process(12), also the pH of the medium change during the process. This change depends on the type of electrode material and initial pH. In this study the pH was studied in the range (3-11), the solution was adjusted to the desired pH for each experiment by adding HCl or NaOH, the pH of the solution increased by about (1-2 unit) at the first

(2-3 minutes) and then decreased. The effect of pH on the percent recovery is plotted in figure (7), from this figure it can be seen that the removal rate increased with a decreased in the pH. When pH was 6 the reaction was so fast that it takes only (90 minutes) to reach (85 %) removal efficiency. At pH higher than 10 it took about 30 minutes more than that when pH about 6 to achieve nearly the same percent recovery, this due to that when the pH is lower than 6 Al(OH)₃ is insoluble from (Al⁺³) and when it is higher than 8 Al(OH)₃ is insoluble from [Al(OH)₄]⁻ and because Al(OH)₃ has major role in removing of phenol, thus when pH of solution in the range (6-8) phenol removal is higher [9].

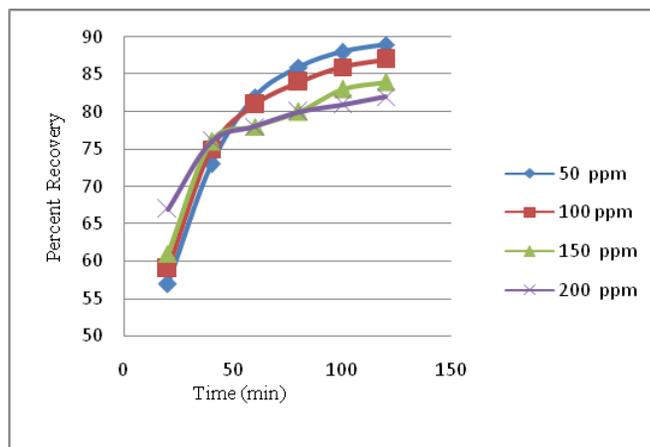


Fig.6: Effect of initial phenol concentration on the removal efficiency (pH=6, 40 °C, 221 A/m²)

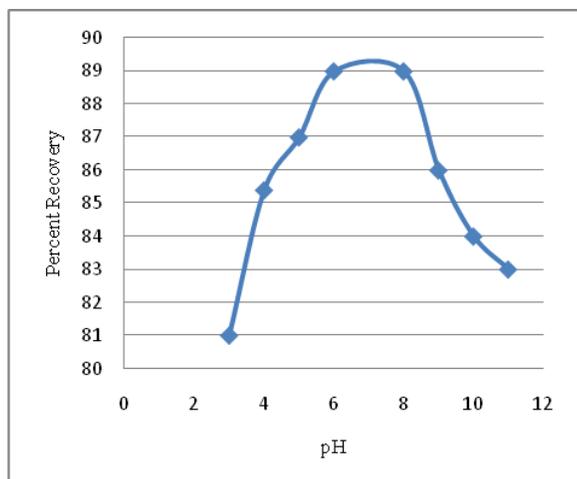


Fig. 7: Effect of solution pH on the phenol removal efficiency (50 ppm, 40 °C, 221 A/m²)

CONCLUSIONS

The removal of phenol from water by Electrocoagulation process was effected by various variables as follows:

1. The removal efficiency increased (33-88 %) with increasing current density in the range (49-221 A/m²) and this was due to that an increase in current density resulted in an increase in the floc production and an increase in the hydrogen generated at cathode which increased the flotation efficiency of the produced sludge.
2. With increasing initial phenol concentration the time required for process should increase too, but that higher initial concentrations of phenol were reduced in relatively less time than the lower concentrations.
3. The best removal achieved when the pH of solution in the range (6-8).
4. With respect to the electrode sizes, the best removal obtained at the higher electrode surface area and lower spacing between the electrodes due to greater dispersion of bubbles throughout the reactor.
5. A good agreement between the theoretically calculated amount of Al dissolved and the experimentally weight value.

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