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Research Article

Mixed Herbal Oil Processing Factory Wastewater Treatment by Pilot-scale Electrocoagulation Unit: Cost Analysis

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Abstract

The study aims; i) to determine the optimum operating conditions for the treatment of wastewaters of mixed vegetable oil (hazelnut oil, sunflower oil, soybean oil, corn oil and canola oil) processing factory effluents by electrocoagulation (EC) method; and ii) to compare currently operated biological WWTP with proposed EC system via cost analysis. Cost analysis shows that EC system's monthly operational cost is 1002 $ less than the current wastewater treatment plant in operation. The factory's wastewaters have already been treated by classical activated sludge system with removal efficiencies below 50%. However, proposed EC system reveals 87.32% COD, 51% TN and 88% TP removal with optimum pH of 7-8 with 3 minutes reaction time and optimum current density of 250 A.

Keywords: Electrocoagulation; Herbal Oil Wastewaters; Pilot-Scale Treatment Plant; Cost Analysis

Introduction

Electrocoagulation process is a treatment method that includes various complex physical and chemical treatment mechanisms such as flotation, coagulation, flocculation, adsorption, redox reactions, particle trapping, and flotation. The electrocoagulation reactor is an electrochemical cell composed of anodes and cathodes. During the reaction, the iron or aluminum on the surface undergoes oxidation to become iron and aluminum cations. Thus, the coagulation process is carried out by utilizing the iron and aluminum ions formed during the anodic reactions without the addition of a chemical to the reaction medium. On the other hand, in the cathode, hydrogen gas is formed by the reduction of water, and the flow of hydrogen gas formed results in the separation of contaminating molecules from water by flotation. The main advantages of such a treatment process over conventional treatment systems are well documented. It can be applied to (over 90% removal efficiency) both domestic and industrial wastewater with high performances (textile [1,2], [3]), tannery [4], food processing [5], petrochemical [6], metal plating [7]. It is also possible to treat leachate originating from landfills [8]. In addition to high purification performance disinfection effect of HOCl is seen in the treated water as chlorine gas (Cl_2) is formed due to oxidation of chloride in the anode when chlorine salt (NaCl) is used as an electrolyte [9].

The reactor voltage of 1.2 V, the current density of 10-40 mA/m2, the pH values of 4, 6, 7 and 9, reaction time of 2-30 min and iron and aluminum electrode material were chosen for an electrocoagulation process in the form of a preliminary treatment before the treatment of olive oil production wastewater [10]. In the experiments, two different combinations of Fe/Al and Al/Fe were applied. The optimum time for this experimental study was found as 10-15 min. In a short time like two minutes, the efficiency of color removal was found to be as high as 78% with an iron electrode and 82% with aluminum electrode. The recovery efficiencies reached to 96% with 10-30 min. In another study treatment of leachate wastewater from landfill with very high pollution by electrocoagulation using aluminum and iron electrodes were investigated. In this study, the electrocoagulation method and chemical coagulation method are compared. It was stated that in chemical coagulation process, 22% COD was obtained with iron electrode and 33% COD removal with aluminum electrode [8].

This study aims; i) to determine the optimum operating conditions for the treatment of wastewaters of mixed vegetable oil (hazelnut oil, sunflower oil, soybean oil, corn oil and canola oil) processing factory effluents by electrocoagulation (EC) method; and ii) to compare currently operated biological WWTP with proposed EC system via cost analysis.

Methodology

Pilot-scale EC Plant

The pilot-scale plant consists of i) a pre-reservoir in which the wastewater is stabilized, pH and conductivity values are measured, where polymer, acid/base and electrolyte (NaCl) are added; ii) electrocoagulation reactors with vertically placed anode and cathode electrodes selected according to wastewater characteristics; iii) Filtration unit separating solid and liquid phases and iv) Treated wastewater reservoir as shown in Figure 1.

Simple electrocoagulation cell consists of an anode and a cathode submerged in an electrolyte. By applying current anode undergoes oxidation and cathode undergoes reduction. The electrochemical reactions of M metal with anode and cathode are as follows [5].

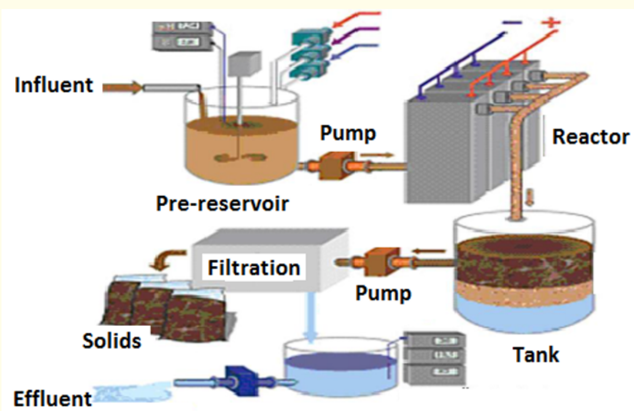

Figure 1: Pilot-scale EC plant.

Anode:

$M \rightarrow M^{n}++ ne-$ ....(1)

$2H_2O \rightarrow 4H++ O_2(g) + 4e-$ ....(2)

Cathode:

$M^{n}+ + ne- \rightarrow M$ ....(3)

$2H_2O+ 2e- \rightarrow H_2(g) + 2OH-$ ....(4)

In this study, the effect of current, pH and reaction time on recovery efficiency was determined by using 37.5cmX14cmX0.5cm iron and aluminum electrodes as anode and chromium material as cathode immersed in 22 cm^3 reactor. After determining the optimum current, optimum pH and appropriate polyelectrolyte type, the efficiency of EC treatment under optimum conditions were monitored by COD, TN and TP measured by DRLANGE–XION500 spectrophotometer.

Characteristics of wastewater

The characteristics of influent wastewater are presented in Table 1.

Character	Value
COD (mg/L)	14200
TN (mg/L)	239.2
TP (mg/L)	186
Conductivity (µ/cm)	5560
pH	3

Table 1: Characteristics of wastewater.

Cost analysis

The amount of sludge is calculated by the amount of dissolved iron and aluminum electrode by Faraday's law. Finally, cost analysis is performed by considering the consumption of electricity, maintenance and repair costs, operating costs, labor costs, analysis cost, chemical cost (polyelectrolyte and caustic lime). The total operational cost has been calculated for a pilot scale EC treatment plant with 1 m^3 of wastewater per day including labor, energy consumption, polyelectrolyte consumption, lime consumption, analysis and maintenance costs.

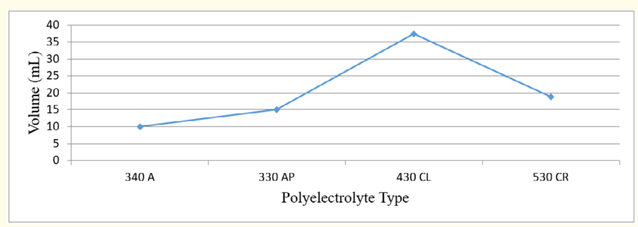

Figure 2: Sludge production according to polyelectrolyte type.

Results and Discussion

Optimum polymer experiments

At the beginning of experiments anionic and cationic polymers were tested for the selection of suitable polymer and it was observed that the most suitable polymer was anionic ENFLOC 330 polymer since the most stable floc was obtained with it. After selection of polyelectrolyte raw wastewater was fed to EC reactors with its original pH and 200 A current was applied. The influent pH and COD value which is a key factor in wastewater treatment was measured as 1 to 3 and 14200 mg/L, respectively. Table 2 gives the COD value with changing currents and electrical inputs in 1 minute reaction time.

	COD (mg/L)	Inf. pH	Adjusted pH	Conductivity (µ/cm)	Energy (V)	Reaction time (min)
Influent	14200	<3		5560		
200A effluent	7100	<3	10	5800	4.0	1
300A effluent	6950	<3	10	5720	3.8	1

Table 2: Current optimization.

Optimum Current Experiments

The electrical inputs of 3, 4, 4.7 and 5.5 Volts and current densities of 1200, 200, 250 and 300 Amperes were used. In order to determine the optimum current value, the current between 100A and 300A and the 1 minute reaction time were applied and effluent COD concentrations were monitored. As Table 3 implies a higher reduction in the COD of herbal wastewater effluents was observed at 4.7 and 5.5 volts.

	COD (mg/L)	Influent pH	Adjusted pH	Conductivity (µ/cm)	Energy (V)	Reaction time (min)
Influent	14200	<3		5560		
100A effluent	7050	<3	10	5300	3	1
200A effluent	7100	<3	10	5800	4.0	1
250A effluent	6550	<3	10	5450	4.7	1
300A effluent	6950	<3	10	5500	5.5	1

Table 3: Effluent COD values at various current density values.

After these tests, the effluent pH was set to 7 and effluent COD values were investigated at various current values. As Table 4 implies, the most efficient values were achieved by 250A and 300A and these values were used as a basis of the study.

Optimum reaction time experiments

Table 5 shows COD values obtained at reaction times ranging from 2 to 6 minutes at 250 A and pH 7. It was found that the best removal efficiency was achieved at 3 min reaction time and optimum energy was observed as 250 A and pH 7. Table 5 also shows TN and TP removals under optimum conditions.

	COD (mg/L)	Inf. pH	Adjusted pH	Conductivity (µ/cm)	Energy (V)	Reaction time (min)
influent	14200	<3		5560		
250A effluent	6100	<3	7	5610	6.3	1
300A effluent	-	<3	7	5650	7.0	1

Table 4: pH 7 experiments.

Reaction time (min)	COD (mg/L)	COD removal Efficiency (%)	TN (mg/L)	TN removal Efficiency (%)	TP (mg/L)	TP removal Efficiency (%)
Influent	14200	-	239.2	-	186	-
2	2200	84.45	105.2	56.2	103	45
3	1800	87.32	90.8	62.3	21.8	88

Table 5: COD, TN and TP removal efficiencies at 250A and pH7.

It was observed that 250 amperes gave the highest yield at pH 7 and the reaction times were tested according to these values. 300A tests were observed to cause burning and deterioration in the water structure.

Sludge amount

The amount of sludge was calculated by the amount of dissolved iron and aluminum electrode by Faraday's Law (ΔM=MAl/nf, ΔM=Dissolved Al and Fe; M=Molecular weight of Al and Fe; n = moles of electrons; f = Faraday's constant (96487 c/mol). The calculated amount of sludge with different electrolyte types was given in Figure 2.

Cost analysis

Cost analysis of currently operated activated sludge wastewater treatment plant

The currently operated wastewater treatment plant is the classical activated sludge system. According to the information provided by the wastewater treatment plant administrative office personnel cost is 8800 TL (2479 $)/ month (4 workers), the daily wastewater flow rate is 3.8 ton/h, energy cost is 3530 TL (994 $), amount of used polyelectrolyte is 4.5 kg/month, amount of used lime is 10 kg/month, analysis cost is 175 TL (49 $)/month and maintenance cost is1250 TL (352 $)/year.

Cost analysis of pilot plant wastewater treatment plant

Under optimum conditions of 250 A, 3 min reaction time and pH 7, a total cost of pilot scale system was calculated as follows. W=AxV=250x6.3=1575 Watt = 1.575 kW/hr consumption. Total power requirement of the 1 hour work end facility (see Table 6) is 2.25+1.575 = 3.825 kW. When the hourly treatment capacity of the facility was calculated as 4 m^3, the amount of energy for 1 m3 wastewater treatment was calculated as 3.825/4 = 0.956 kW. 10% lime was used for pH adjustments. The consumption of lime solution used in pH adjustments in 500 mL water was found to be around 14 mL. This corresponds to 0.028 mL in 1 mL. An amount required to raise the pH in the wastewater was calculated as 28000 mL. 28000 x 0.1 = 2800 g lime needs to be used. The anionic polyelectrolyte used in the experiments was prepared and dosed as a solution at a concentration of 3/1000 and 3 g of polyelectrolyte per cubic meter was used. Table 7 gives total cost.

Equipment name	Energy
Tank mixer	0.50 kW
Reactor pump	0.50 kW
Dosage pump	0.25 kW
Vertical mixer	0.25 kW
Polymer mixer	0.25 kW
Total	1.75 kW

Table 6: Equipment and their power.

	Amount	Unit price	Total price
Energy cost	0.956 kW	0.42 TL/ kW	0.40152 TL (0.11 $)
Lime consumption	2.8 kg	0.25 TL / kg	0.7 TL (0.2 $)
Polyelectrolyte consumption	0.003 kg	0.67 TL /kg	0.00201 TL (5.66x10^{-4} $)
Total			**1.10353 TL (0.31 $)**

Table 7: Treatment cost of 1 m^3 of wastewater.

Cost comparison analysis

Table 8 gives a comparison of the pilot EC treatment system and current classical activated sludge wastewater treatment plant in terms of direct and indirect cost items.

	Classical biological WWTP		EC pilot WWTP	
	m^3 cost	monthly cost for 2000 m^3/month plant	m^3 cost	monthly cost for 2000 m^3/month plant
Personnel (4 workers)	-	8800 TL (2479 $)	-	8800 TL (2479 $)
Energy cost (per m^3)	1.765 TL (0.497 $)	3530 TL (994 $)	0.3066 TL (0.086 $)	613.20 TL (173 $)
Polyelectrolyte cost (per m^3)	0.0011 TL 3.1x10^{-4} $)	2.2 TL (0.62 $)	0.0020 TL (5.63x10^{-4} $)	4 TL (1.13 $)
Lime cost (per m^3)	0.922 TL (0.26 $)	1844 TL (519 $)	0.70 TL (0.197 $)	1400 TL (394 $)
Analysis cost	-	175 TL (49 $)		175 TL (49 $)
Maintenance cost	-	1250 TL (352 $)		1050 TL (296 $)
Total		15601 TL (4394 $)		12012 TL (3392 $)

Table 8: Cost comparison analysis.

Conclusion

Waste oils having an eco-toxic character are responsible for approximately 25% of the receiving body's contamination. Wastewater containing waste oil has a negative impact on the ecosystem by preventing oxygen transfer from the air by covering the water surface like a film layer. Waste oils cause blockages in sewage systems and wastewater treatment plants, increasing the pollution load and ultimately increasing the cost of operation and maintenance.

Herbal oil processing factory is producing several types of oil with very high organic matter and making traditional biological treatment ineffective. For this reason, the treatment options of the wastewater of the oil factory are focused on the chemical and advanced treatment methods and the treatment options which will reach the sewage discharge standards. This is exactly the method of electrocoagulation that can provide this deficiency.

This study showed that mixed herbal oil wastewaters can be treated effectively by EC with a small area as compared to currently operated conventional activated sludge system. EC pilot plant system established at oil plant reached 87% COD, 62.3% TN and 88% TP removals under the optimum values of 250A current, pH 7 and the reaction time of 3 min. It is clear that the EC system was effective in treating mixed oil wastewater. The currently operated wastewater treatment plant is a classical activated sludge treatment plant and it is insufficient to treat wastewater with around 40% efficiency in measured parameters.

Another important objective of this study was to compare economically the EC pilot plant established with the currently operated wastewater treatment plant. As a result of the analysis and calculations made, it was determined that the monthly cost of the EC system was 12042 TL (3392 $) and the monthly expense of the classical activated sludge system being operated was 15601TL (4394 $). As a result of all these findings, it has been found that the EC system achieves high efficiency in mixed oil treatment and the monthly operation cost is 1002 $ less.

The main advantages of the EC process established are high treatment performance and disinfection effect of HOCl with less cost. It is well known that hydrogen gas is crucial in removing the suspended solids towards the surface and also it is an alternative energy source for a sustainable environment. This study will be followed by an approach towards hydrogen energy production determination by mixed herbal wastewater effluents.

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