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TREATMENT OF SULLAGE WASTEWATER BY ELECTROCOAGULATION USING STAINLESS STEEL ELECTRODES

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ABSTRACT

The study was made for the treatment of sullage wastewater using electrocoagulation technique with stainless steel electrode as sacrificial anode in bipolar connection system. The effects of operating parameters such as pH, voltage and electrolysis time on the removal of COD, BOD and SS were investigated. The optimum value for each operating parameter was experimentally determined. The optimum values of voltage, initial pH and electrolysis time were found to be 8V, 6.8 and 30 mins, respectively. The experiments revealed that COD, BOD and SS in aqueous phase were effectively removed. The analysis of the treated water showed that the maximum COD, BOD and SS removal efficiencies were 92.71%, 88.76% and 93.1%, respectively at optimum conditions. The wastewater was very clear and its quality meets the discharge standard. Consequently, the electrocoagulation process can be considered as a reliable, safe and cost effective method for the treatment of sullage wastewater.

Key words: Electrocoagulation, Sullage wastewater, Stainless steel Electrodes, Electrolysis time, Voltage.

INTRODUCTION

Domestic wastewater (sullage) originates from bathrooms, clothes washing, sinks but does not include wastewater from kitchen sinks, dishwasher and toilet. Domestic wastewater needs to be properly managed to minimize health risks and degradation of environment. The reuse of reclaimed domestic wastewater will lower fresh water demand, increase groundwater recharge, reduce strain and cost on municipal wastewater is essential in order to establish proper treatment method. Domestic water decomposes much faster than black water, which implies rapid decomposition of domestic wastewater pollutants and enhances prevention by water pollution. Domestic wastewater contains fewer pathogens than

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black water and care should be taken while displacing it to environment. If domestic wastewater is stored for 24 hrs, then it exhibits the properties of black water. Hence, domestic wastewater should not be stored but it can be temporarily stored in a surge tank with adequate treatment. The treated domestic wastewater can used for recharging the groundwater gardening, plant growth and for toilet use. Hence, there is a need to study the characteristics of domestic wastewater from residential areas. The aim of this work was to access the sullage wastewater quantity from house in average to find out the characteristics of wastewater, design of reactor to meet the treatment requirements of the wastewater characteristics, to device a batch model to treat the sullage wastewater, to introduce an innovative method to treat the above water using electrocoagulation and to find out the outlet water characteristics. At end of the study, suitable suggestion will be depicted to establish a method for the safe disposal of the domestic wastewater that would be very much useful for the society as a whole.

Theory of electrocoagulation

Electrocoagulation is a process consisting of creating metallic hydroxide flocs inside the wastewater by electrodes solution of soluble anodes made of aluminium or iron. The main reactions occurring during electrocoagulation produce aluminium ions at the sacrificial anode and hydroxide ions as well hydrogen gas at the cathode. Electrcoagulation involves several chemical and physio-chemical phenomena due to electrolysis. Generally three steps occur in a successive way

- Formation of coagulants by dissolution of anode (sacrificial electrode),
- Coagulation of contaminants and particulate suspension and breaking of emulsions
- Aggregation of the destabilized by flocculation or adsorption on the metal hydroxide flocs or its polymers.

The colloidal particles forming a stable suspension are destabilized by addition of metal cations. The most commonly used metals are iron and aluminum because of their low costs and their high valence ($^{+}$III). Their positive charge interacts with negative charge of contaminants and compresses their diffuse double layer, and thus reduces the electrostatic interparticle repulsion and even eliminates it. Consequently, coagulation can occur with formation of flocs that entraps and bridges colloidal particles still remaining in the aqueous medium. Electrochemical reactor is fed by a DC generator. The amount of metal

electrolyzed is dependent on current supplied by the generator. This amount can be expressed by Faraday's law.

$$m_{theoritical} = \frac{I \times t \times M}{n \times F} \quad \ldots(1)$$

where, m is the theoretical quantity of electrode material dissolved in grams

I is the current intensity (A)

t is the time in second

M is the molar mass of the metal of electrode in grams

n is the number of electrons in oxidation/reduction reaction

F is the Faraday's constant, 96,500 $Cmol^{-1}$

The theoretical mass calculated by the Faraday's law can be different from the real mass. Indeed, only a part of the over potential will be used for electrolysis, the rest will be dissipated by Joule effect and used to overcome the over voltage at both electrodes. The applied over potential is thus written

$$\eta AP = \eta Mt + \eta k + \eta IR \quad \ldots(2)$$

where, ηAP is the applied over potential

ηMt the concentration overvoltage

ηk the kinetic over potential and

ηIR the over potential caused by solution ohmic drop

Concentration over potential, also called the mass transfer or diffusion overvoltage, is due by the concentration gradient near the electrode caused by electrolysis. It can be reduced by eliminating this gradient by increasing the transport of cations from the anode surface to the bulk solution, i.e. by increased mixing between the electrodes.

Kinetic over potential (also called activation potential) has its origin in the activation energy barrier to electron transfer reactions.

The ohmic drop depends on the following operating parameters: Inter-electrode

distance, the electrode surface and solution conductivity. Control of these parameters can reduce it. It can be expressed as follows:

$$\eta IR = \frac{I \times d}{A \times k} \quad \ldots(3)$$

where, d is distance between electrodes (cm)

A is active surface of electrode (cm^2)

K is solution conductivity (Scm^{-1})

Mechanism of electrocoagulation

The passage of current by means of electrode generates *in situ* coagulants by electrically dissolving ion electrodes. Stainless steel electrode predominantly releases Fe^{+2} ions. The metal ions generation takes place at the anode, while hydrogen gas is released from the cathode. The chemical reactions taking place at the electrodes are given as follows:

For stainless steel anode

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

At alkali conditions

$$Fe^{2+} + 3\,OH^- \longrightarrow Fe(OH)_2$$

At acidic conditions

$$4\,Fe^{2+} + O_2 + 2\,H_2O \longrightarrow 4\,Fe^{3+} + 4\,OH^-$$

In addition of oxygen evaluation

$$2\,H_2O - 4\,e^- \longrightarrow O_2 + 4\,H^+$$

For stainless steel cathode

$$2\,H_2O + 2\,e^- \longrightarrow H_2 + 2\,OH^-$$

Freshly formed amorphous $Fe(OH)_2$ has large surface areas that are beneficial for rapid adsorption of soluble organic compounds and trapping of colloidal particles.

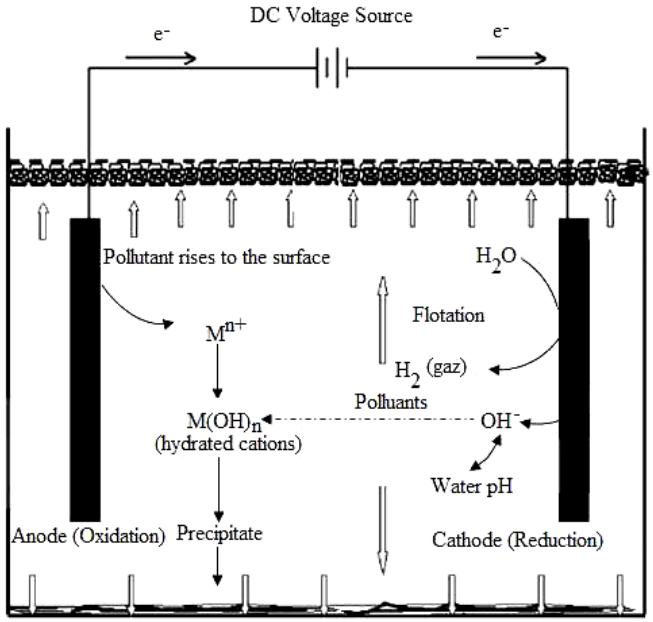

Fig. 1: Mechanism of electrocoagulation

EXPERIMENTAL

Material and methods

Characteristics of sullage water

The wastewater was collected from residential areas, Coimbatore, Tamilnadu, India. The characteristic of the wastewater is shown in Table 1. All reagents were of analytical grade and were used without further purification. Solutions were prepared out room temperature with deionised water.

Table 1: General characteristics of the raw sullage wastewater

S. No.	Parameters	Unit	Values
1.	pH	-	6.8
2.	Turbidity	NTU	97
3.	COD	mg/L	350
4.	BOD	mg/L	210
5.	SS	mg/L	150

Electrocoagulation was carried out in batch reactor with a 500 mL capacity as shown in Fig. 1. The electrocoagulation reduction was performed with a bipolar mode and with stainless steel-stainless steel anode-cathode electrodes. The outer electrodes were connected to the DC power supply (Beetec RPS-3002, 30V-2A) and electrodes with dimensions 70 mm x 50 mm x 3 mm, were placed in vertically at a fixed distance 40 mm. The contents of the electrocoagulation reactor were gently aerated with magnetic stirrer (Elico GI631). In this study, in each run the voltage was varied to a desired value of 4, 6 and 8V. Before starting-up the process, the electrodes were cleaned with 1 M H_2SO_4 and rinsed with deionized water to eliminate impurities from the surface of the electrodes. The effects of electrocoagulation time, current density and initial pH. After the experiment, the treated sample was taken kept undisturbed for 20 min in order to allow the flocs to settle. Subsequently, after settling the sample of supernatant was collected to perform the analysis of SS, COD and BOD.

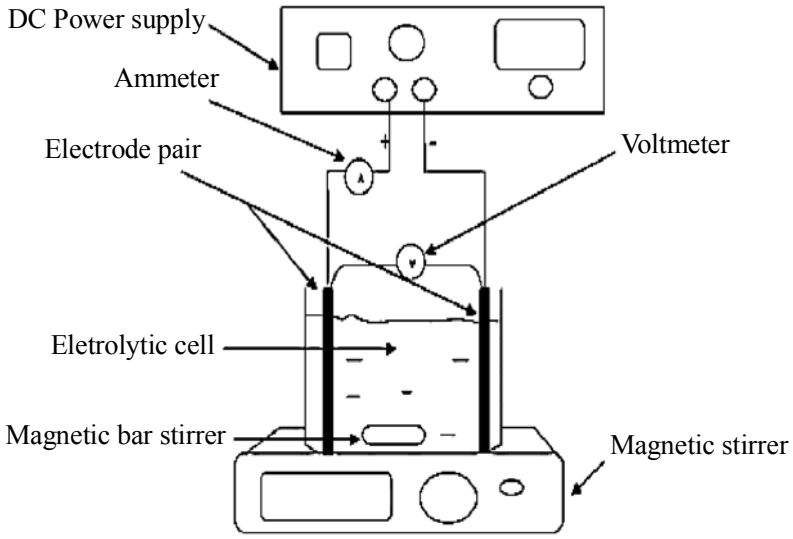

Fig. 2: Schematic diagram of electrocoagulation cell

Analysis

The pH measurements were made on Systronics (Rainbow 5200). The chemical oxidation demand of the wastewater sample was determined by dichromate reflux method, using COD digestion apparatus (Ajay, Sigma 81355) suspended solids were calculated by gravimetric method.

RESULTS AND DISCUSSION

Experiments were performed to study the electrocoagulation process in batch mode of operation for the treatment of sullage wastewater. The various parameters such as pH, voltage and electrolysis time were varied to explore their effect on COD, BOD and SS removal. Initially, the experiment was carried out without adjusting pH of raw wastewater at pH 6.8 with varying voltage. The COD reduction for 549 mg/L to 238 mg/L, 112 mg/L and 40 mg/L thereby giving 56.64%, 79.95% and 92.71% COD removal efficiencies, respectively for 4V, 6V and 8V at 30 minutes shown in Fig. 3.

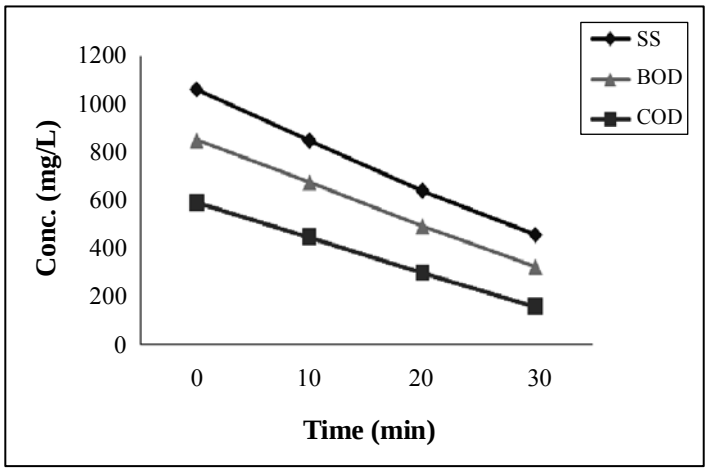

Fig. 3: Effect of time on COD, BOD and SS (4V)

Table 2: The chemical analysis of sullage wastewater

Sample No.	Sample volume (mL)	Electrode distance (4 cm)	Voltage (volts)	Parameters	Initial conditions	Electrocoagulation time		
						10 min	20 min	30 min
1	250	4	4	pH	7.9	7.1	6.32	6.1
				COD (mg/L)	590	447	299	159
				BOD (mg/L)	260	228	193	165
				SS (mg/L)	210	172	148	132
				Current density (A/m^2)	-	1115.7	1231.5	1347.1

Cont…

Sample No.	Sample volume (mL)	Electrode distance (4 cm)	Voltage (volts)	Parameters	Initial conditions	Electrocoagulation time		
						10 min	20 min	30 min
2	250	4	6	pH	7.4	6.59	6.31	6.2
				COD	510	337	238	110
				BOD	248	210	157	134
				SS	195	154	128	107
				Current density (A/m^2)	-	1417.1	1511.5	1615.3
3	250	4	8	pH	6.8	6.5	6.39	5.4
				COD	549	238	112	40
				BOD	240	193	156	110
				SS	200	174	138	100
				Current density (A/m^2)	-	1617.4	1782.2	1891.1

Table 3: Percentage of the decrease in wastewater samples after electrcoagulation treatment

Sample No.	Voltage (volts)	Time (min)	% of COD Reduction	% of BOD Reduction	% of SS Reduction
1	4	10	24.27	14.3	18.9
		20	49.32	25.76	29.52
		30	73.5	36.53	37.14
2	6	10	36.0	25.32	31.2
		20	53.33	46.69	45.12
		30	78.43	62.1	63.7
3	8	10	56.64	44.79	41.2
		20	79.95	61.25	62.5
		30	92.71	88.76	93.1

The BOD reduced from 240 mg/L to 192 mg/L, 156 mg/L and 110 mg/L there by being 44.79%, 61.25% and 88.76% efficient in reducing BOD from wastewater, respectively for 4V, 6V and 8V at 30 mins shown in Fig. 4.

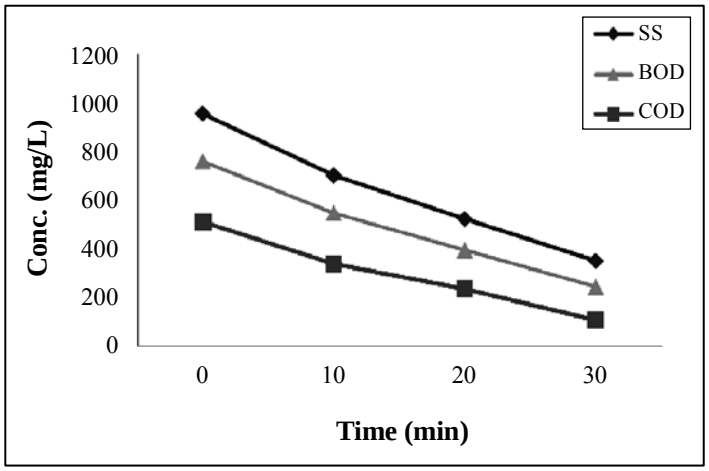

Fig. 4: Effect of time on COD, BOD and SS (6V)

The SS reduced from 200 mg/L to 174 mg/L, 138 mg/L and 100 mg/L there by being 41.0%, 62.5% and 93.1% efficient reducing SS from wastewater, respectively for 4V, 6V and 8V shown in Fig. 5.

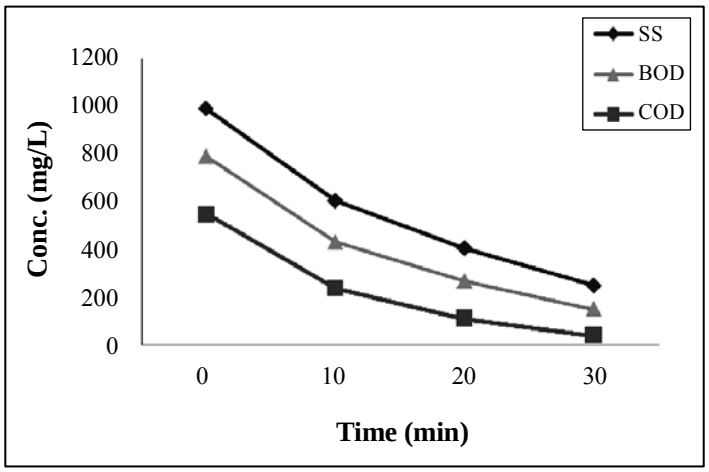

Fig. 5: Effect of time on COD, BOD and SS (8V)

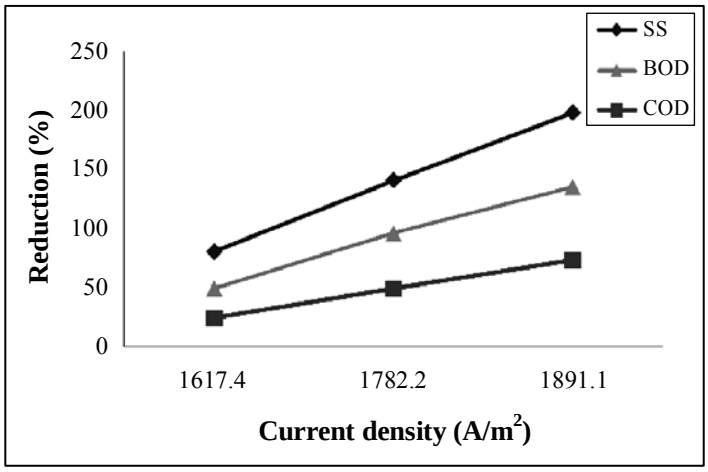

Fig. 6: Effect of current density on COD, BOD and SS (4V)

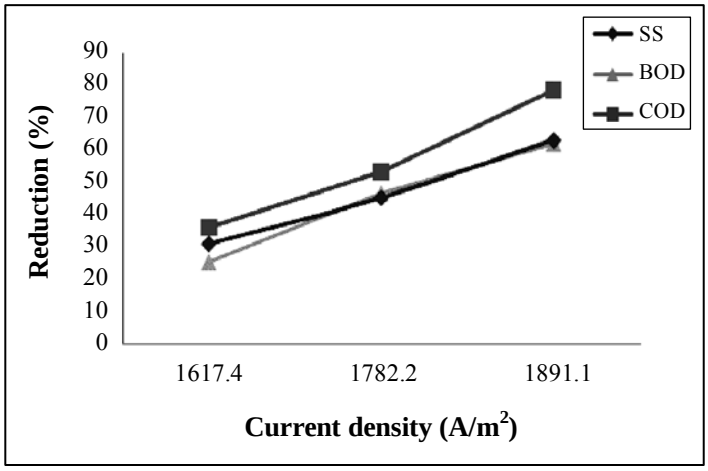

Fig. 7: Effect of current density on COD, BOD and SS (6V)

Further, the experiment was carried out by increasing pH to 7.4 with different voltage 4V, 6V and 8V and maximum COD removal efficiencies of 36%, 53.33% and 78.43%, respectively were obtained for 30 mins, which is shown in Fig. 10. The maximum BOD removal efficiencies of 25.32%, 46.69% and 62.1% for 30 mins were obtained and these are shown in Fig. 11. When the experiment was carried out by further increasing the pH to 7.9 with varying voltage 4V, 6V and 8V the maximum COD removal efficiencies were found to be 24.27%, 49.32% and 73.5%, respectively for a 30 mins shown in Fig. 9.

Similarly, the maximum BOD removal efficiencies obtained were 14.3%, 25.76% and 36.53% for 30 mins shown in Fig. 9.

From the above analysis, it was found that maximum COD removal efficiencies of 92.71%, BOD removal of 88.76% and SS removal of 93.1% were obtained at optimum operating parameters of pH 6.8, 8V and 30 mins of electrolysis duration. At the operating conditions COD reduced from 549 mg/L to 40 mg/L, BOD reduced from 240 mg/L to 110 mg/L and SS reduced from 200 mg/L to 100 mg/L.

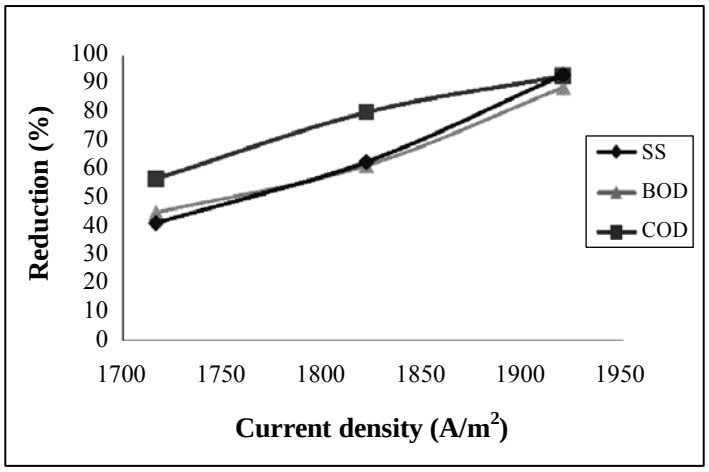

Fig. 8: Effect of current density on COD, BOD and SS (8V)

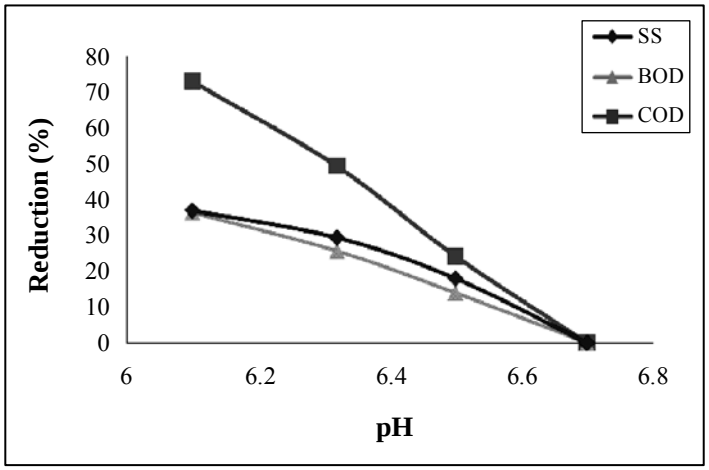

Fig. 9: Effect of pH on COD, BOD and SS (4V)

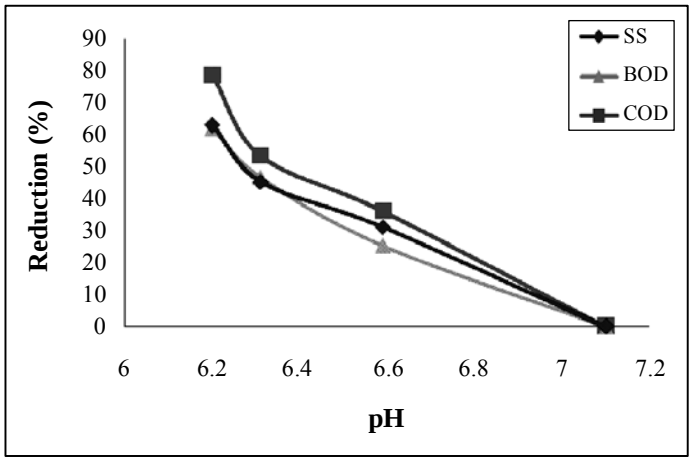

Fig. 10: Effect of pH on COD, BOD and SS (6V)

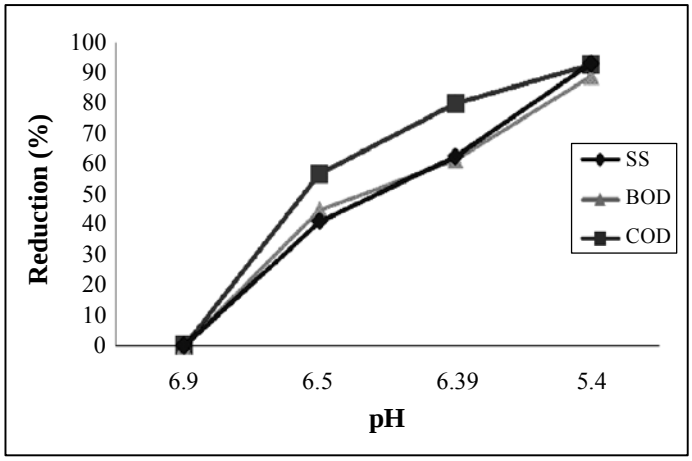

Fig. 11: Effect of pH on COD, BOD and SS (8V)

CONCLUSION

The electrocoagulation was an effective method for the treatment of sullage wastewater using SS304-SS304 as anode and cathode electrodes. The removal efficiency of COD, BOD and SS depends on release of ions from the electrode. This can be done by increasing the current density, were the amount of ions generated can be increased, which leads to higher efficiency. Using various operational variables such as electrocoagulation time, current density and pH were investigated. The result shows that the maximum COD, BOD and SS removal efficiency were 92.71%, 88.76% and 93.1%, respectively at optimum conditions.

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