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Electrocoagulation treatment of rice grain based distillery effluent using copper electrode

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ABSTRACT

This article reports the electro coagulation treatment (ECT) of rice grain based distillery effluent in a batch reactor using copper electrodes. ECT with copper electrode is a better alternative as compared to aluminum/iron electrode to treat rice grain based biodigester effluent (BDE), due to less power consumption at acidic pH which is the main attraction of the present work. The ECT in batch mode is conducted in a 1.5 L cubical shape electrocoagulation reactor using four-plate configurations. A current density of 89.3 A/m^2 and pH 3.5 is found to be optimal, providing a maximum chemical oxygen demand (COD) and colour removal of 80% and 65%, respectively. At pH 3.5 electrode loss was 3.667 mg/L and power consumption was 11.42 WH/L. It is noted that treated slurry at pH 8 has shown best settling characteristic, which decreases with decrease in pH. Thermogravimetric analysis indicates that the residues obtained from the EC treated BDE may be used as fuel.

1. Introduction

Ethanol has been considered as a renewable fuel that is better for the environment than traditional gasoline. In India, ethanol blended gasoline (5–10%) is used as a motor fuel in automobiles [1]. More than 75% of ethanol is produced from sugar cane molasses and sugar beet, which is not available throughout the year. Therefore other alternatives such as rice, wheat, corn etc. are also considered for ethanol production. Rice is one of the major crop and readily available India, and hence, could be used for production of ethanol.

Ethanol is produced by fermentation of rice grain in fermentation broth, which contains 5–14% (v/v) of ethanol. The ethanol is separated from the top of the distillation column and the liquid obtained from the bottom is called spent wash (SW). Rice grain based SW contains high COD (10,000–40,000 mg O_2/L) and BOD (3000–15,000 mg O_2/L) [2]. Due to its high organic content it is first treated in an aerobic biodigester where 50–70% COD and 60–80% BOD is reduced. The effluent obtained from biodigester is called biodigester effluent (BDE), which still contains high COD (5000–15,000 mg O_2/L) and BOD (1000–5000 mg O_2/L) [2]. The high COD and BOD of the distillery SW and BDE are due to the presence of a number of organic compounds like polysaccharides, reduced carbohydrate, proteins, melanoidin, waxes etc. BDE is often dark brown in colour and may be due to the presence of malanoidin. Colour is another serious problem, since the colour interferes with the absorption of sunlight are responsible to reduce the natural process of photochemical reactions for self purification of the surface water. Therefore, the removal of colour and COD from the rice grain based BDE acquires immense importance from the environmental point of view. Furthermore, regulatory agencies in India have notified discharge water quality standards for release into surface water (BOD < 30 mg O_2/L, COD < 100 mg O_2/L) and sewer (BOD < 100 mg O_2/L, COD < 300 mg O_2/L) [3], therefore, effective treatment method is needed to reduce pollution load of BDE.

Various treatment methods reported to treat BDE includes coagulation [4], thermolysis [5], adsorption [6] and electrochemical treatment [2,7,8]. Among all these treatment methods, ECT is a better method due to its several advantages such as, less additional chemical (coagulant) requirement, easier installation, more cost effective, low value of secondary pollution, odor and colour removal, and lower residence time [9].

In our previous study [10] potential of elctrocoagulation process for the removal of colour and COD of rice grain based BDE was demonstrated. It was shown that under optimal initial pH (pH_0)

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Table 1
Electrocoagulation used for treatment of distillery wastewater.

Type of waste water	Current density or Current	Anode-Cathode	pH	time (time)	Removal efficiency	References
Distillery biodigester effluent	89.3 A/m^2	Al-Al	8	120 min	93	[2]
Distillery biodigester effluent	156.25 A/m^2	SS-SS	5	60 min	63.96	[8]
Distillery biodigester effluent	99 A/m^2	Fe-Fe	8	120 min	93	[10]
Distillery spent wash	14.285 mA/cm^2	Rd-SS	5.5	180 min	39.66	[11]
Distillery spent wash	0.817 A/cm^2	Al-Al, Al-Fe, Fe-Fe	3	120 min	81.3, 71.8, 52.4	[12]
Distillery spent wash	0.03 A/cm^2	Al-Al	3	120 min	72.3	[13]
Winery waste water	2 A	Al-Al	–	40 min	98.2	[14]
Distillery spent wash	6 A/dm^2	Graphite-Graphite	6.9–7.2	180 min	85.2	[15]

of 8 and current density of 99 A/m^2, about 93% COD removal and 87% colour removal could be obtained. Optimum conditions of others related work and electrode used by different investigator is summarized in Table 1.

In this background the present work aims to study the effect of pH, current density (CD) and electrolysis time (t) for the removal of COD and colour. The electrode loss and power consumption was calculated during ECT process. Besides, settling characteristics of the EC treated BDE is also reported.

2. Experimental

2.1. Effluent and its characterisation

The BDE used in the present study was obtained from Chhattisgarh Distillery Pvt., Ltd., Kumhari, Chhattisgarh, India. To maintain constant characteristics of BDE, the sample was stored at 4 °C in a deep freezer. Reactor was made up of Perspex glass and copper plate was used as electrode. The effluent was characterized in terms of various parameters namely, COD, colour, total solids, total dissolved solids, total suspended solids, reduced carbohydrate, sulphate, and chloride etc., as per standard method of analysis [16]. The main characteristic of the original and treated effluent studied in the present study is given in Table 2.

2.2. Experimental method

The lab-scale batch experimental setup (Fig. 1) was used for the EC studies. In a 1.5 L reactor (made up of Perspex glass), 1.4 L of BDE was taken and its pH was maintained by using H_2SO_4 (1 M) and NaOH (1 M) solutions. Four electrodes made up of copper plates (2 mm thickness having dimension of 8 cm × 7 cm) were used in the experiments hence the total effective surface area of each electrode was 56 cm^2. All electrocoagulation reactors (ECR), irrespective of their shape and size are basically electrochemical cells. All such reactors consist of a pair(s) of electrodes (of any desired shape) in contact with the wastewater. The basic concept of ECT consists application of direct current from an external source between the sacrificial anode and the cathode (not necessarily made up of inert material) to enhance contact between the dispersed particles in the solution and promote in-situ coagulation. A distance of 2.0 cm was maintained between the two electrodes in the EC reactor. A distance of 1.5 cm was provided between the bottom of the electrodes and the reactor bottom for easy stirring. Mixing in the reactor was carried out by teflon coated stirring bar installed between pretreated plate and the bottom of the cell. The electrodes were cleaned with 10% dilute HCl solution after the completion of each run, followed by washing with tap water and drying at 50–60 °C for further experiment. The current density was adjusted and kept constant by means of a digital direct current (D.C.) power supply (0–30 V, 0–5 A) source. During the experiments after certain time interval, samples were taken in a test tube and allowed for settling to remove sludge. At last the supernatant liquid obtained was used for various parameters (COD and colour) analysis.

3. Result and discussion

It has been reported that the distillery effluent contains carbohydrate, proteins and melonoidin [17]. Carbohydrate contains negatively charged carboxylic and hydroxyl functional groups. The melonoidin and colloidal surfaces also have negative charges. All these take part in the electrocoagulation reduction process. Data investigated for BDE are presented in Table 1.

During the EC process involving copper electrode, (Cu^{2+}) were released at the anode, while at the cathode, typical H_2 production occurs. Many reactions take place in the EC reactor with copper electrodes as shown below [18]:

At copper anode

$$2Cu \rightarrow 2Cu^{2+} + 4e- \quad (1)$$

Table 2
Typical composition of biodigester effluent before and after treatment by EC at CD = 89.3 A/m^2, electrode distance = 2 cm.

Parameters	Biodigester effluent	EC treated BDE at optimum condition (pH 3.5)
COD	11,500	2300
TDS	43,245	1523
TSS	39,331	4515
TS	82,576	6038
Reduced carbohydrate	517	Not found
Protein	165	79
Chlorine	161	55
Phosphate	0.05	nil
Total hardness	10,220	244
Sulphate	4718	613
pH	7.8	8.0
Colour	Blackish brown	Light yellow (transparent)
Absorbance at wavelength = 475 nm	0.831	0. 299
Colour (PCU)	398	139.3

*All value in mg/dm^3 except pH and colour.