Optimization of Electrocoagulation Process for the Treatment of Dairy Wastewater using Response Surface Methodology

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***Abstract*– The present work aims to study the treatment of simulated dairy waste water (SDW) by electrocoagulation process using aluminum electrodes in a laboratory scale batch reactor. Box–behnken design and response surface methodology was employed for optimization of 3 responses: chemical oxygen demand (COD), anode consumption (AC), specific electrical energy consumption(SEEC). Three factors namely current density, pH& conductivity with each factor at three levels were used. Regression model equations were developed which were validated by high R^2 values of 97.98%,98.60%,99.82% for COD, anode consumption and SEEC respectively. Optimization was targeted for maximum COD removal and minimum operating cost. The optimized conditions as suggested by the model were: applied current density—2.228mA/cm^2, pH-7.01, and conductivity-1921.81µS/cm. Optimum COD removal efficiency were 78.71% while anode consumption and SEEC was 0.072mg/mg COD and 0.070J/mg COD respectively.**

Keywords*– *Dairy wastewater, electrocoagulation, response surface methodology, aluminum electrodes.

I. INTRODUCTION

The dairy industry generates strong wastewaters characterized by high biological oxygen demand (BOD) and chemical oxygen demand (COD) concentrations reflecting their high organic content [1] which are difficult to treat properly because of their complex behavior [2]. The milk-processing industries discharging untreated wastewater can cause serious environmental problems such as the increase in the microbial biomass, depletion of the dissolved oxygen concentration, mushroom and algae proliferation, deposits of mud and eutrophication of receiving surface waters[3].

Dairy wastewaters are generally treated by aerobic /anaerobic biological processes. Biological processes require big spaces and long time of treatment and generate a great amount of sludge [1]. Among physicochemical methods, electrocoagulation (EC) is one of the processes which offer high removal efficiencies in compact reactors, with simple equipments for control and moderate operating cost. Since dairy wastewater is considered as stable oil in water effluents, EC process could be used for their treatment[2].

EC method implies sacrificial anode, where the metal cations of coagulation are released in situ when the electric current is applied. At the same time, the reactions of electrolysis generate hydrogen bubbles to cathode and oxygen bubbles to the anode, which favors flotation of the particles[3].

In the present study, box-behnken design (BBD) and response surface methodology (RSM) has been used for the modeling, analyzing and optimization of responses: COD, anode consumption(AC), specific electrical energy consumption(SEEC) for the process parameter settings: current density, pH, and conductivity.

II. MATERIALS AND METHODS

A. EC apparatus

EC experiments were conducted in a lab-scale mono-polar batch EC reactor having an effective volume of 2 L. Two aluminum electrodes of size 10*7.8*0.3 cm and surface area of 156 cm^2 were used. The electrode gap was 2 cm for all experiments. Electrodes were connected to a DC power supply (Testronix, 0-30V,0- 5A). Magnetic stirrer at 50 rpm was used to stir the solution to get homogeneous wastewater-flocs mixture. The batch EC cell with mono-polar electrode connection is shown in Fig.1.

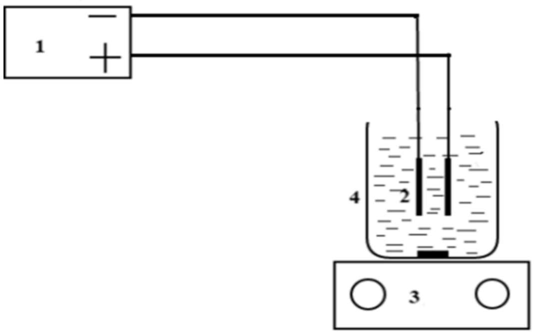


Fig.I. Diagram of the experimental setup. (1): DC power supply, (2): electrodes, (3): magnetic stirrer, and (4): EC reactor.

B. Experimental procedure

To prevent any change in the composition of wastewater throughout the experiments, freshly prepared simulated dairy waste water (SDW) was used. The electrodes were abraded with sand paper before EC experiments to remove scale and were dipped in HCl (35%)for 10 minutes followed by a water wash for the removal of impurities from the electrode surface. 0.1N H_2SO_4 and 0.1N NaOH solutions were used to adjust the pH to a desirable value before the beginning of the experiment. The electrolysis time was 30 minutes for all experiments which was determined experimentally. The conductivity of the wastewater was adjusted to the desired value by addition of NaCl. Samples were taken at the end of the experiments from the reactor. All the samples were filtered with WHATMAN 1.2μm filter paper.

TABLE I: CHARACTERISTICS OF DAIRY EFFLUENTS

Characteristics	Value
Chemical oxygen demand (COD) (mg/L)	1300±50
Biochemical oxygen demand(BOD) (mg/L)	950±60
Total solids(mg/L)	1791±150
Total dissolved solids(mg/L)	1062±140
Total suspended solids(mg/L)	729±10
Turbidity(NTU)	470±10
pH	7.60±0.20
Conductivity(μS/cm)	750±10

Anode consumption was calculated by weighing the anode before and after the run. The various characteristics of dairy effluent are shown in Table I.

C. Experimental design and data analysis

Total 17 experiments were designed based on three factors and three level box-behnken designs based on RSM to optimize the output parameters. The experimental matrix comprised of 12 factorial runs and five centre point runs. The experiments were performed triplicates, and an average value of each response has been presented. Experimental data was analyzed using Design Expert 10.0.0 trial version. The three settings for each factor have been based on previous studies and experimental investigations. Table II gives variables and their levels.

TABLE II. FACTORS AND THEIR LEVELS USED FOR EC TREATMENT OF SDW

Variables	Factor	levels		
		-1	0	1
A	Current density (mA/cm^2)	1.92	2.40	2.88
B	pH	6.00	7.00	8.00
C	Conductivity(μS/cm)	1000	1500	2000

III. RESULTS AND DISCUSSION

Table III gives the experimental design matrix and the experimental results which are obtained from EC experiments as well as their corresponding predicted values for the input parameters.

A. Development of regression model equation

The software suggested quadratic models to obtain regression equations for all the three responses: %COD removal, anode consumption& SEEC. The regression model equations for COD, anode consumption and SEEC in terms of coded factors are given by "(1)", "(2)" and "(3)" respectively.

%COD removal =77.53 +1.45*A +1.58*B +5.72*C +0.35*A*B- 0.58*A*C-0.16*B* C-7.71*A^2-6.48*B^2-3.27*C^2 (1)

TABLE III. EXPERIMENTAL DESIGN MATRIX AND THE EXPERIMENTAL RESULTS ALONG WITH THEIR PREDICTED VALUES

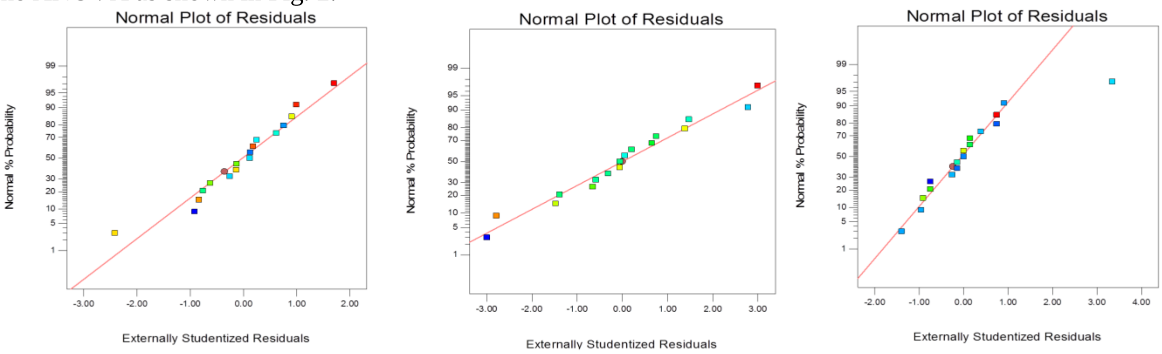
Run	A: Current density	B: pH	C: Conduc-tivity	%COD removed		AC(mg/mg COD)		SEEC(J/mg COD)	
				experimental	predicted	experimental	predicted	experimental	predicted
1	2.40	6	1000	60.44	60.32	0.107	0.109	0.196	0.196
2	1.92	7	1000	58.08	58.80	0.089	0.092	0.144	0.142
3	2.88	7	1000	62.98	62.86	0.143	0.139	0.249	0.248
4	2.40	8	1000	64.31	63.80	0.119	0.119	0.184	0.185
5	1.92	6	1500	61.28	60.66	0.073	0.069	0.084	0.084
6	2.88	6	1500	62.66	62.86	0.116	0.118	0.166	0.168
7	1.92	8	1500	63.34	63.12	0.082	0.079	0.081	0.079
8	2.88	8	1500	66.13	66.72	0.131	0.134	0.159	0.159
9	2.40	6	2000	71.58	72.08	0.079	0.078	0.093	0.092
10	1.92	7	2000	71.31	71.40	0.055	0.059	0.065	0.066
11	2.88	7	2000	73.87	73.14	0.120	0.116	0.124	0.124
12	2.40	8	2000	74.83	74.92	0.096	0.094	0.089	0.089
13	2.40	7	1500	77.81	77.53	0.088	0.088	0.098	0.099
14	2.40	7	1500	74.95	77.53	0.086	0.088	0.095	0.099
15	2.40	7	1500	76.35	77.53	0.087	0.088	0.096	0.099
16	2.40	7	1500	78.92	77.53	0.089	0.088	0.105	0.099
17	2.40	7	1500	79.64	77.53	0.091	0.088	0.100	0.099

Anode consumption=0.088+0.026*A+ 6.625E-003*B-0.014*C+1.500E-003*A*B +2.750E-003*A*C+1.250E-003*B*C +6.900E-003*A^2+5.400E-003*B^2 +6.650E-003*C^2 (2)

SEEC=0.099+0.041*A-3.250E-003*B-0.050*C-1.000E-003*A*B-0.012*A*C +2.000E-003*B*C+0.014*A^2+9.350E-003*B^2+0.032*C^2 (3)

B. Validation of the model

The ANOVA table for %COD removal, anode consumption, and SEEC is given in Table 4. It can be seen that both linear and quadratic terms are effective factors on the COD concentration. For SEEC and anode consumption, linear term is highly significant. For anode consumption and COD, A, B, C, A^2, B^2, C^2 are significant model terms. For SEEC, A, B, C, AC, A^2, B^2, C^2 are significant model terms. This is for significance level at $\alpha = 0.05$. Regression model equations are validated by high R^2 values of 97.98%, 98.60%,99.82% for COD, anode consumption, and SEEC respectively. According to normal probability plot of externally studentized residuals, the quadratic model well satisfied the ANOVA as shown in Fig. 2.



A: COD B: anode consumption C: SEEC

Fig. II. Normal probability plot of residuals for COD, anode consumption and SEEC

TABLE IV. ANOVA FOR %COD REMOVED, ANODE CONSUMPTION AND SEEC.

Source	**%COD removed**				**Anode consumption**				**SEEC**			
	Sum of squares	**df**	**Mean square**	**F value**	**Sum of squares**	**df**	**Mean square**	**F value**	**Sum of squares**	**df**	**Mean square**	**F value**
Model	820.48	9	91.16	37.68	7.988E-003	9	8.876E-004	54.72	0.040	9	4.451E-003	422.14
Linear	298.89	3	99.63	41.17	7.374E-003	3	2.458E-003	151.45	0.033	3	0.011	1043.64
Interaction	1.97	3	0.655	0.27	4.550E-005	3	1.517E-005	0.93	5.490E-004	3	1.830E-004	17.36
Quadratic	471.56	3	157.19	64.95	5.095E-004	3	1.698E-004	10.46	5.641E-003	3	1.880E-003	178.37
Residual	16.94	7	2.42		1.136E-004	7	1.623E-005		7.380E-005	7	1.054E-005	
Cor Total	837.41	16			8.102E-003	16			0.040	16		

Therefore, current density is more effective than pH in COD removal as the level changes from -1 to 0. At higher pH, COD removal decreases as the soluble species become predominant [4]. Excess current can break the flocs and increase TDS of the solution. SEEC is defined as the amount of electrical energy consumed per unit mass of pollutant removed. Anode consumption and SEEC increases with increase in current density and remains almost unaffected by pH.

(2). Effect of current density and conductivity

The conductivity of the solution is a very important parameter as the removal efficiency of the pollutant, and operating costs are directly related to the solution conductivity. From Fig.3, it can be seen that COD removal increases with increase in conductivity reaching to saturation beyond 1500µS/cm. When chlorides are presents in the solution the products from the anodic discharge of chlorides are Cl_2 and OCl^-. The OCl^- itself is a strong oxidant which is capable of oxidizing organic molecules present in wastewater. So, added NaCl not only increases the conductivity but also contributes strong oxidizing agents [5]. From "(1)", as the level changes from -1 to 0, the sign of the linear coefficient of conductivity is less than that of quadratic coefficient of current density. So, current density is more effective than conductivity in COD removal. Similarly, as the level changes from 0 to 1 conductivity is more effective than current density in COD removal. Anode consumption and SEEC decreases with increase in conductivity. This is because of reduction in cell voltage at constant current density [4]. As the applied voltage of the system is reduced, the amount of electrode consumed is also reduced [6].Also, their interaction effect is significant for SEEC.

C. Effect of various parameters

(1). Current density and pH

From Fig.3, COD removal increases with increase in current density upto an optimum value after which it starts decreasing. A similar effect can be seen with pH. From "(1)", the quadratic coefficient of current density is more than pH and both are of same sign.

D. Optimization of the process

Optimization was targeted for maximum COD removal and minimum operating cost.The results of the optimization with the desirability of 0.925 are presented in Table V.

TABLE V.OPTIMIZATION RESULTS

Variables	Unit	Values from optimization
Current density	mA/cm^2	2.23
pH		7.01
Conductivity	µS/cm	1921.81
COD	mg/l	78.71
Anode consumption	mg/mg COD	0.072
SEEC	J/mg COD	0.070

IV. CONCLUSION

In the present study, box-behnken design (BBD) design was employed for modeling, analyzing and optimization of the EC process for the treatment of dairy wastewater using aluminum electrodes.The quadratic models for the responses were validated by high R^2 values of 97.98%, 98.60%,99.82% for COD, anode consumption, and SEEC respectively. The analysis result shows that current density, pH, and conductivity have significant effects on COD removal, anode consumption, and SEEC. Optimization of the EC process gave COD removal of

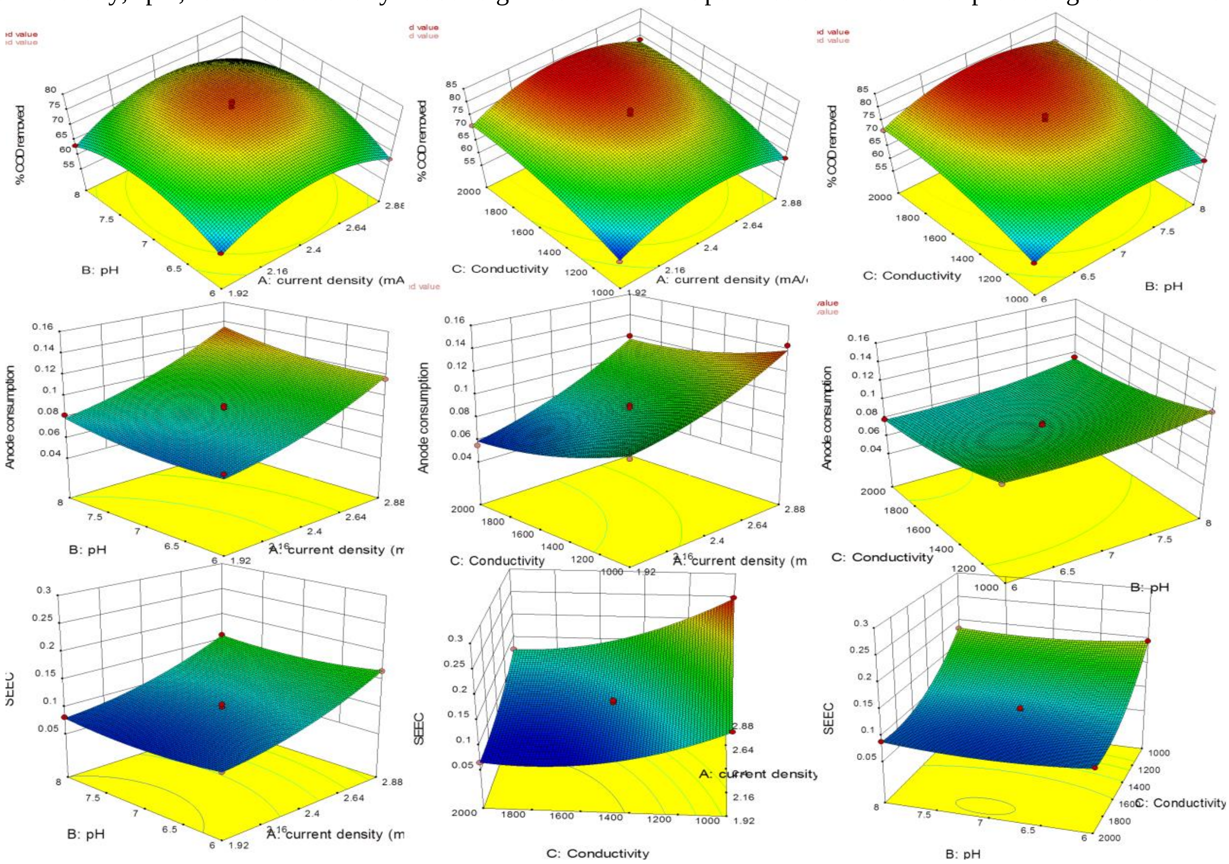


Fig. III.Effect of variables on the COD removal, anode consumption and SEEC.

78.71% for anode consumption of 0.072mg/mg COD and SEEC of 0.070J/mg. Thus, EC process can be coupled with the biological treatment methods for further efficiency.EC process can efficiently reduce the dairy pollutants and reduce the large size of biological reactors, treatment time and sludge handling issues.

VI. ACKNOWLEDGEMENT

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