Control of Electrocoagulation Batch Reactor for Oil removal from Automobile Garage Wastewater

Harinarayanan Nampoothiri M.G\textsuperscript{a}, Manilal A.M\textsuperscript{b,}\textsuperscript{*}, Soloman P.A\textsuperscript{c}

\textsuperscript{a}M.Tech Scholar, Department of Chemical Engineering, GEC Thrissur, 680009, India
\textsuperscript{b}Assistant Professor, Department of Chemical Engineering, GEC Thrissur, 680009, India,
\textsuperscript{c}Professor and Head, Department of Chemical Engineering, GEC Thrissur, 680009, India,

Abstract

Wastewater from Automobile garages and workshops is an important contributor to the water pollution. Oil is one of the major content of wastewater from vehicle garages. The work focuses on the design of an electrocoagulation (EC) reactor for the removal of oil content in wastewater from Automobile garages with automation and control for efficient operation. The samples for the study were collected from Kerala State Road Transportation (KSRTC) Thrissur depot. Experimental study has been conducted to investigate the influence of various factors affecting electrooagulation. Major factors selected were current density, time of EC, salt concentration and pH on oil removal. The influence of these factors on percentage oil removal was found to be non-linear. Experiments were designed by Response Surface Method (RSM) and a nonlinear empirical relationship between percentage oil removal and input parameters was obtained. Responses were optimized using MINITAB software and these values were used in the control purpose. Control and automation of electrocoagulation process was developed with reaction time in the batch electrocoagulation reactor as the controlling variable. Power supply to the electrodes was also controlled with a level switch. Both inlet and outlet control were proposed for the efficient run of the batch EC reactor.

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1. Introduction

Environmental pollution is a potential threat to living conditions in the earth. Overpopulation has resulted in the larger utilization of natural resources which paved the way for the increase of pollutions in the environment. Water conservation is one area which requires a significant attention[1]. In day to day life water is polluted in many ways. Industries are one of the major sources of water pollution. [2]. High levels of pollutants are present in industrial wastewater. Along with different metals and nonmetals, oil and grease has contributed largely to the water pollution. [3]. The impact of oil content in water is seen by modern scientists and separation of oil from water hence become highly important. Both the oil and grease are important for many fields like automotive, flour mills and so forth. The automobile service stations use large amount of water for washing and maintenance activities. Thus the mixing of water with oil particles is easily possible in these units. Water discharging from these automobile workshops and garages in large quantities causes water pollution especially in urban arenas[4] Water treatment is unnoticed in most of these vehicle garages and workshop. The task centers on enforcing an effective method for water treatment from automobile garages.

The main objective of the present work is to design a control system for the batch electrocoagulation system for the oil removal process. Different parameters that influence the oil removal by electrocoagulation were analyzed for developing the control system for the optimal operation of the batch system. Wastewater from Kerala State Road Transport Corporation (KSRTC) Thrissur depot is taken for analysis. KSRTC depot Thrissur uses large quantities of water (10000 liters per day) and large quantity of oil contained wastewater is brought forth. Oil is one of the major content in this kind of wastewater. There are several methods available for oil removal from effluent, such as physical treatment, chemical handling, biological treatment, membrane treatment [3]. Electrocoagulation technique (EC) is one of the modern technologies in wastewater treatment. It is the combination of chemical and physical treatments [5]. It is an electrochemical method which applies the basic precepts of traditional water treatment [6]. In contrast to coagulation method in which particles known as coagulants are added to aggregate the pollutant, EC uses electrodes to release coagulants. Electrocoagulation has been under research for removal of pollutants from wastewater. Electrocoagulation includes the advantages like huge sludge production, process inefficiency, and necessity of further treatment mechanism. Electrocoagulation was successfully conducted for wastewater treatment. [7-13]. Hence the possibility of electrocoagulation treatment for smaller water treatment units like automobile garages is investigated. The viability of control and automation of the Electro coagulation based water treatment is investigated. Experimental design using Response Surface Methodology, a statistical tool, is used to develop combinations of influencing parameters for conducting the batch experiments. RSM can be used for empirical modeling of the system relating input and yield parameters. [14-16] A mathematical relationship between output term and input values with non linear terms can be developed using RSM.

2. Materials And Methods

2.1 Wastewater Characteristics

The samples were collected from the workshop of the KSRTC Thrissur depot. Around 10000 litres of water per day is used for different purposes in the KSRTC workshop. The samples were analyzed. The COD of the sample1 was 540 mg/L a second sample was 1600 mg/L. Total solids were 220mg/L, Total Dissolved Solids (TDS)was 40mg/L and Total Suspended Solids was 180 mg/L. The pH of the water samples examined and found to be 6.2. All content in the sample was examined by fluorescence spectroscopy. The fluorescence peak is held between 300-340 nm. The excitation wavelength of oil is 337 nm. The density of the feed was 970 g/l.
2.2 Electrocoagulation Set Up

Figure 1: Schematic of EC reactor-1.Powersupply with indication 2. Reactor 3. Magnetic stirrer 4. anodes(mild steel/aluminium) 5. cathodes(stainless steel) 6. Water to be treated.

Experimental set up for electrocoagulation is shown in figure 1. The design of reactor for electrocoagulation was the first step of the work. A reactor with a capacity of 2 litres and dimension of 20cm×10cm×10cm was selected. The reactor was made of Plastic. The wastewater fed into the reactor for the electrocoagulation treatment. EC consists of sacrificial electrodes which act as a source of coagulants. These were made of mild steel and Aluminium. In anode metallic cations are generated and in cathode hydrogen is generated. The overall reaction produces metal hydroxides. These adsorb the oil present in the wastewater. Two different metals were selected as anodes, mild steel and aluminium. The cathode was stainless steel. Electrodes were arranged in parallel arrangement. 5 anodes made of mild steel and five cathodes made of stainless steel were used in the first phase and aluminium electrodes were used instead of mild steel anodes in the second phase. All electrodes were identical in dimensions, 8cm×5cm. Total electrode area for 10 electrodes was 400 cm² or 4 dm². Number of electrodes were selected and arranged with minimum gap with the objective for efficient EC operation. A DC power supply was used to provide current and potential across the electrodes. APLABS regulated DC power supply was used for the purpose. The input voltage specification was 0-230 V AC, and output voltage was 0-30 V DC. The current output of the power supply specified at 2 A. The power supply had short circuit protection which helped in protecting it from probable contacts with electrodes. A magnetic stirrer was provided in the reactor with varying rotational speeds. Magnetic stirrer was an integral part of the mechanism because proper contacts of electrodes with wastewater and to reduce the IR drop of the system.

2.3 Response Surface Method (RSM)

The combinational effect of influencing parameters on removal efficiencies of electrocoagulation was analyzed using Response surface method (RSM). RSM is an advanced statistical tool, and which is implemented using MINITAB software. A response surface design refers to a set of advanced design of experiments (DOE) techniques which help in experimental analysis and response optimization. There are two types of response surface designs; central composite design and Box-Behnken design. Box-Behnken method is selected for further analysis. It requires a lesser number of runs compared to central composite method. RSM can give an empirical model relating the input parameters and output value. A mathematical relationship can be represented as follows Let the output be y and input parameters are \( x_1, x_2, x_3, ..., x_n \) we can relate input and output as
\[
Y = f(x_1, x_2, x_3, ..., x_n) + k
\]
Where k is a constant

RSM can analyze the effect of each coefficient associated with each parameter. Four parameters viz., current density, time, salt concentration and pH were analyzed with their linear relation, square relation and combinational
2.4 Control and Automation of EC Process

A robust control mechanism is required for the better performance of the electrocoagulation process. The reactor used is a batch reactor. Controlling parameter can be one of the four parameters under the test; current density, time, salt concentration and pH. Current density and time are the two parameters that are viable to control. In batch EC reactor the process can be controlled using the time inside the electrocoagulation reactor calculated for an optimum value of oil removal. RSM based empirical relationship can be used as the model for developing the control structure.

The proposed control model is shown in the block diagram below figure 2. The control is implemented as two parts; inlet control and outlet control. A level switch was implemented as the key part of inlet control. Both the inlet flow and power supply to electrodes were controlled by the level switch. It closes the inlet ON OFF valve and turn on the power supply to the electrodes when the level reaches the maximum value. The objective of the inlet control is to prevent the loss of electric power and makes the process more efficient.

The outlet control includes a data acquisition system, software including mathematical model, a timer, and solinoid valve. These parameters were fed into the data acquisition system: current density, pH and salt concentration. For measuring the current density, digital systems can be used for the measurement and transmission of current value. Salt concentration is measured in terms of conductivity. The analog to digital modules interfaces the system with a digital computer. The model was programmed such that it can return optimum time for the given input data to get maximum oil removal. The maximum removal value used was the value obtained from optimization.

Figure 2 : Block diagram for automation and Control of the electrocoagulation reactor

3. Results and Discussions

3.1 Experiments Designed with Response Surface Methodology-Results and Analysis

Design of experiments tool is used to design the combination of input parameters for system design. 27 sets of experiments were proposed by Response Surface Method of Design of Experiments tool. Experiments were carried out using both mild steel and aluminium electrodes. Following is the analysis of EC runs.
The COD analysis of feed wastewater and sample treated with EC using mild steel and Aluminium were analyzed. Chemical Oxygen Demand of the water was reduced after the experimental runs. The percentage oil removal was affected by the change in each of the four variables. With the increase in input parameter values, percentage COD values were improved. pH was an exception. Maximum COD removal was observed at pH 7 and was decreased with variations from pH 7. The parameters were interdependent. The current density values were affected by salt concentration values. The time of the experiments was widely affected by variations in every parameter, which was a large dependent variable because the pH was highly independent term. Figure 3 show the plot of the COD values of the feed and the experimentally treated water for EC using Aluminium. Maximum oil removal obtained with EC using Aluminium was 89% and mild steel was 80.05%. The removal efficiencies were more with EC using Aluminium than mild steel. For EC using mild steel, the efficiencies were declined sharply with a reduction in the parameter values. Interdependence of current density and salt concentrations were observed.

3.5 Analysis of Final pH Value.

Analyzing the final value of pH and the comparison of the same with the feed pH value is significant (fig 4) because the electrocoagulation includes reactions that can change the pH of the solution. The final pH value was deviated from feed pH value. The final pH values were shown more change with initial acidic pH values. For example, in the electrocoagulation experiments using mild steel the final pH value was incremented by more than a unit value with an initial pH value 5. The Final pH value was increased with almost every experiment.
3.6 Statistical Analysis Of The Results

The response Surface tool was used for developing a mathematical relationship between input parameters and output percentage removal. In addition to the ability of designing the experiments, it can also be used for obtaining an empirical modelling.

A mathematical relationship was obtained by percentage removal as a function of Current Density, Time, Salt Concentration and pH.

Mathematical relationship for EC using Aluminium

Percentage oil removal = 46.521 + (−87.896 × CD) + (−1.010 × t) + (−95.262 × SC) + (11.674 × pH) + (33.748 × CD × CD) + (−0.082 × t × t) + (144.917 × SC × SC) + (−1.548 × pH × pH) + (2.172 × CD × t) + (−93.351 × CD × SC) + (9.3865 × CD × pH) + (2.75 × t × SC) + (0.48 × t × pH) + (11.83 × SC × pH)

(2)

Mathematical relationship for EC using mild steel

Percentage oil removal = −254.882 + (−110.850 × CD) + (1.134 × t) + (166.365 × SC) + (85.759 × pH) + (−35.785 × CD × CD) + (−0.114 × t × t) + (−96.525 × SC × SC) + (−6.606 × pH × pH) + (3.73 × CD × t) + (21.099 × CD × SC) + (18.755 × CD × pH) + (3.653 × t × SC) + (0.137 × t × pH) + (−17.240 × SC × pH)

(3)

Table 1: Statistical analysis of coefficient values calculated using the RSM method for EC using Aluminium R-square value is 95%

<table>
<thead>
<tr>
<th>Term</th>
<th>Coefficient</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>46.521</td>
<td>2.734</td>
<td>0.018</td>
</tr>
<tr>
<td>a1</td>
<td>−87.896</td>
<td>−2.768</td>
<td>0.017</td>
</tr>
<tr>
<td>a2</td>
<td>−1.010</td>
<td>−0.801</td>
<td>0.439</td>
</tr>
<tr>
<td>a3</td>
<td>−95.262</td>
<td>1.626</td>
<td>0.130</td>
</tr>
<tr>
<td>a4</td>
<td>11.674</td>
<td>3.93</td>
<td>0.002</td>
</tr>
<tr>
<td>a5</td>
<td>33.748</td>
<td>1.289</td>
<td>0.281</td>
</tr>
<tr>
<td>a6</td>
<td>−0.082</td>
<td>−1.79</td>
<td>0.09</td>
</tr>
<tr>
<td>a7</td>
<td>147.917</td>
<td>1.289</td>
<td>0.222</td>
</tr>
<tr>
<td>a8</td>
<td>−1.548</td>
<td>−8.433</td>
<td>0.000</td>
</tr>
<tr>
<td>a9</td>
<td>2.1719</td>
<td>1.605</td>
<td>0.134</td>
</tr>
<tr>
<td>a10</td>
<td>−93.6383</td>
<td>−1.380</td>
<td>0.193</td>
</tr>
<tr>
<td>a11</td>
<td>9.3865</td>
<td>3.469</td>
<td>0.005</td>
</tr>
<tr>
<td>a12</td>
<td>2.7500</td>
<td>1.038</td>
<td>0.320</td>
</tr>
<tr>
<td>a13</td>
<td>0.480</td>
<td>4.594</td>
<td>0.001</td>
</tr>
<tr>
<td>a14</td>
<td>11.83</td>
<td>2.229</td>
<td>0.046</td>
</tr>
</tbody>
</table>

The statistical analysis of the coefficient experimental modeling was done (Table 1). It was given by P, T and F values. For Aluminium, current density, pH, squared coefficient of time, the combinational coefficient of time and pH, current density and pH were having a P value less than 0.05. Similarly, larger the T value, larger will be the effect of the parameter. Hence a P value and T value indicating the similar trend for the coefficients. The ANOVA analysis of the terms is shown in the table 2, indicates the significance of linear and square terms.

Table 2: ANOVA analysis of percentage oil removal EC is used Aluminium

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>14</td>
<td>3695.67</td>
<td>3695.67</td>
<td>263.976</td>
<td>5.19</td>
<td>0.103</td>
</tr>
<tr>
<td>Linear</td>
<td>4</td>
<td>1739.75</td>
<td>1739.75</td>
<td>434.937</td>
<td>8.555</td>
<td>0.002</td>
</tr>
<tr>
<td>Square</td>
<td>4</td>
<td>1557.91</td>
<td>1557.91</td>
<td>389.478</td>
<td>7.65</td>
<td>0.003</td>
</tr>
<tr>
<td>Interaction</td>
<td>6</td>
<td>398.01</td>
<td>398.01</td>
<td>66.335</td>
<td>1.3</td>
<td>0.337</td>
</tr>
<tr>
<td>Residual Error</td>
<td>12</td>
<td>610.63</td>
<td>610.63</td>
<td>50.886</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of fit</td>
<td>10</td>
<td>610.63</td>
<td>610.63</td>
<td>61.063</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pure error</td>
<td>2</td>
<td>0.000</td>
<td>0.000</td>
<td>0.002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>26</td>
<td>4306.30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.8 Response Optimization Using Minitab

Response optimizer is a tool in MINITAB which gives optimized values of input for the required amount of output. RSM gives maximum percentage removal as a combination of the four input parameters. It has given current density value of 0.57A/dm$^2$, time 15 minutes, salt concentration 0.25 gL$^{-1}$ and pH 8.9, for obtaining maximum removal value i.e. 94.82% for EC using Aluminium. For mild steel 81.53% of removal is observed with current density value 0.57 A/dm$^2$, time 14.6 minutes, salt concentration 0.25 gL$^{-1}$ and pH 7.06. This optimized value can be used for further control purposes.

3.10 Prediction of Reaction Time Using Rsm Relationship for Control and Automation

Control and automation were developed by the model explained. A MATLAB program was developed as the function of prediction model was developed. The program includes developing an RSM model to calculate the percentage removal and the maximum percentage removal was developed from the response optimizer of RSM. So a MATLAB program was developed using the RSM model empirical model. A program is given. The program returns the optimum time for maximum removal.

The prediction of time is the pivotal step in the output control which operates a solenoid valve for desalting the EC reactor. The prediction of time was done using the RSM model with the removal oil percentage was set at maximum value given by MINITAB optimizer tool. Model with the values of current density, time and pH was fed as the input values. The proposed Data Acquisition system can practically measure the current density, time, salt concentration values.

3. Conclusion

The work focused on the implementation of a control mechanism in an electrocoagulation batch reactor for the removal of oil and grease from wastewater releasing from the automobile garages. Wastewater from KSRTC Thrissur Depot was treated. COD test and fluorescence spectrometry were the major analysis conducted in the treated water. Electrocoagulation experiments were conducted with Fe and Al electrodes. The important parameters affecting the EC process were analyzed viz., Current density, time, salt concentration and pH. The percentage oil removal was increased with increase in current density, time, salt concentration values. At neutral pH, percentage removal was maximum and was decreased with deviation from the same. Salt Increase in salt concentration has shown increase in the current density value.

Electrocoagulation experiments were designed using Response surface methodology with the help of MINITAB software. For EC using Al electrodes, percentage COD removal in the range of 40-89.2% was obtained. For EC using mild steel percentage COD removal was observed in the range of 11-82%. Initial pH and final pH were analyzed. The final pH was increased after every experiments. This indicates electrocoagulation is a pH incrementing process. Anode weight differences were analyzed to study the impact of Faraday’s law of electrolysis on the oil removal using electrocoagulation. Anode weight loss showed direct relationship with percentage oil removal.

A functional relationship between percentage oil removal and influencing parameters was obtained from RSM. The function included both linear and non linear terms. Statistical and graphical analysis of experimental studies was also obtained from RSM. MINITAB software gave optimum values of output removal based on the experimental observations.

A control structure is proposed for automation and optimization of the process. RSM empirical model was used for developing the control structure. Reaction time in the batch EC reactor was controlled. The inlet flow to the reactor was also controlled with a level switch. The control structure helps in controlling the power supply to electrodes hence current efficiency can also be increased. Thus total efficiency can improve by the implementation of automation and control.
References


