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# TEXTILE WASTEWATER CONDUCTIVITY CONTROL OF ELECTROCOAGULATION PROCESS USING MATLAB / SIMULINK

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**ABSTRACT**

This paper presents an experimental application of PID control to study the electrocoagulation process of textile wastewater. The addition of NaCl solution would also lead to the decrease in power consumption because of the increase in conductivity. Conductivity in electrocoagulation process is difficult to control because of the complex nonlinear behaviour involved. Conductivity changes during the textile wastewater treatment and then temperature of the system is changed, as a result some system properties such as viscosity and density have been changed. According to such changes, efficiency of purification change. As a result, control of conductivity for such a system is necessary. Also this study includes a series of tests in which a PID control was used for conductivity control. Due to the non-linear behaviour of the process, the PID parameter adjusting was very difficult but the obtained results showed that PID control with appropriate parameters is suitable for the electrocoagulation process.

**Keywords**: Electrocoagulation, Conductivity Control, Matlab / Simulink, Wastewater

## 1. Introduction

The large quantity of wastewater discharge from textile industries becomes a very important environmental problem. The wastewater from textile industries has some characteristics such as high or low pH, high temperature and a high concentration of colouring material. Usually the wastewater is taken from finishing and dyeing processes of textile industries and then must be treated before final discharge. If chemical coagulation is treated to purify the wastewater, excessive pollution problem can be observed due to chemical substance added at a high concentration. In that case, several environmental problems can be seen that it must be avoided by electrocoagulation. For this reason, electrochemical coagulation is become more important than others. The characteristics of electrocoagulation are simple equipment and easy operation, brief reactive retention period, decreased or negligible equipment for adding chemicals and decreased amount of sludge (Alinsafia *et. al.*, 2005; Daneshvar *et. al.*, 2003).

Electrocoagulation has significant advantages to eliminate the disadvantages of the classical treatment techniques. Moreover, the mechanisms of electrocoagulation method must be clearly understood so some problems can be raised such as removal of ionic species, particularly metal ions, from wastewater by this technique (Mollah *et. al.,* 2001).

As it is explained before the electrocoagulation method has been successfully used to purify a variety of industrial wastewater. The aim is to form flocks of metal hydroxides within the effluent to be cleaned by electro-dissolution of soluble anodes. Three main stages occur during electrocoagulation such as; electrolytic reactions at the surface of electrodes, formation of coagulants in aqueous phase, adsorption of soluble or colloidal pollutants on coagulants, and removal by sedimentation and floatation (Alinsafia *et. al.*, 2005).The main reactions at the electrodes are:

$Al \rightarrow Al^{3+} + 3e^{-}$ (at anode) (1)

$3H_2O + 3e^{-} \rightarrow 3/2H_2 + 3OH^{-}$ (at cathode) (2)

The destabilized particles then aggregate to form flocks. In the meantime, the small hydrogen bubbles produced at the cathode induce the floatation of most flocks, helping to effectively separate particles from wastewater. So far, the cathode may be chemically attacked by $OH^{-}$ ions generated together with $H_2$ at high pH values.

$2Al + 6H_2O + 2OH^{-} \rightarrow 2\,Al(OH_4)^{-} + 3H_2$ (3)

$Al^{3+}$ (aqua) and $OH^{-}$ ions generated by electrode reactions (1) and (2) react to form various monomeric kinetics (Alinsafia *et. al.*, 2005).

PID control algorithm is shown below. As it is known that $K_C$, $\tau_D$and $\tau_I$ are the proportional control, derivative control and integral control parameters for PID control algorithm. Generally in complex processes such as electrocoagulation processes these parameters are defined with manual tuning (Couchanowr D.R and Koppel L.B., 1985).[4]

$$p=K_c\epsilon+K_c\tau_D\frac{d\epsilon}{dt}+\frac{K_c}{\tau_I}\int_0^t \epsilon dt+p_s \quad (4)$$

The bias $p_s$ can be adjusted. Since the controller output equals $p$ when the error is zero, $p$ is adjusted so that the manipulated variable are at their nominal steady-state values. The controller output depends on the integral of the error signal over time, $\tau_I$ is mentioned to as the integral time or reset time and has units of time. For commercial controllers, controller parameter $\tau_I$ is adjustable. Integral control action is widely used because it offers an essential practical advantage, the elimination of offset. Commercial controllers are presented which run *anti-reset windup*. This feature diminishes reset windup by temporarily halting the integral control action whenever the controller output saturates. The integral action continues when the output is no longer saturated. The *anti-reset windup* feature is sometimes referred to as a *batch unit* because it is required when batch processes are started up automatically. Derivative control mode tends to stabilize the controlled process by providing anticipatory action (Seborg *et. al.*, 1989).

In addition feedback control system has been used large amount in chemical industry. Similarly this process control system was used electrocoagulation processes schematic diagram of the system is shown below. This system is given in Figure 1 as a block diagram.

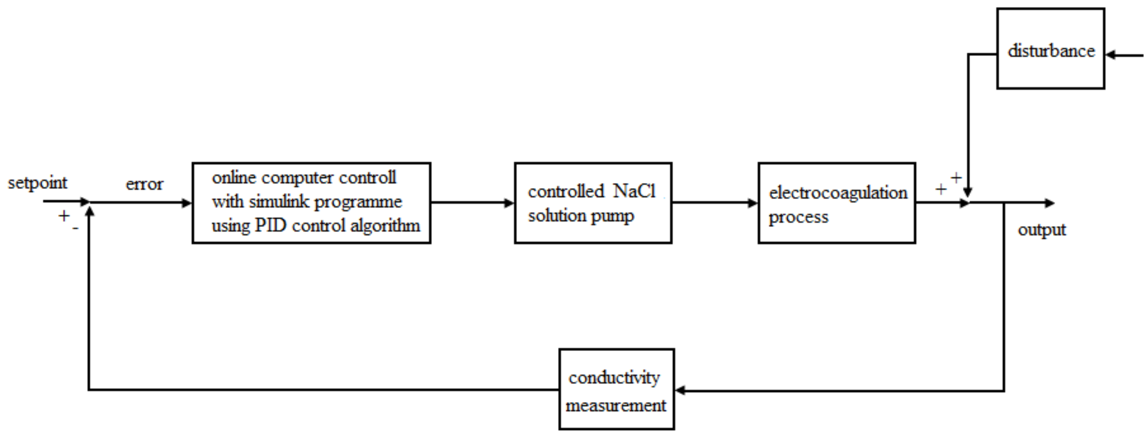



**Figure1**. Feedback control system with block diagram (Bequette, 2003)

For feedback control purposes online computer control system with Simulink programme was used. This computer has the signal from the conductivity meter and after then making necessary calculation, it send the signal to the pump system. This pump sent NaCl solution to the electrocoagulation processes to adjust the conductivity of the system set point.

The present work aims at evaluating the PID control of conductivity for textile wastewater. As it is known that wastewater is containing reactive dyes and such a pollutant in that case it is fairly important to avoid the impurities from effluent. Electrocoagulation method is being used to purify the textile wastewater. Conductivity of such a system is very important to save the energy consumption. The conductivity of wastewater is changing significantly during the electrochemical processes. For this reason, conductivity of wastewater is controlled with PID action.

## 2. Materials and method

The textile wastewater was obtained from a textile factory in Malatya, located in the eastern part of Turkey. The experimental setup is schematically shown in Figure 1. The electrochemical reactor has four mono-polar aluminium electrodes. All electrodes were made from plates with dimensions of 60mm × 60mm × 3mm. The current density was maintained constant by means of a precision DC power supply.

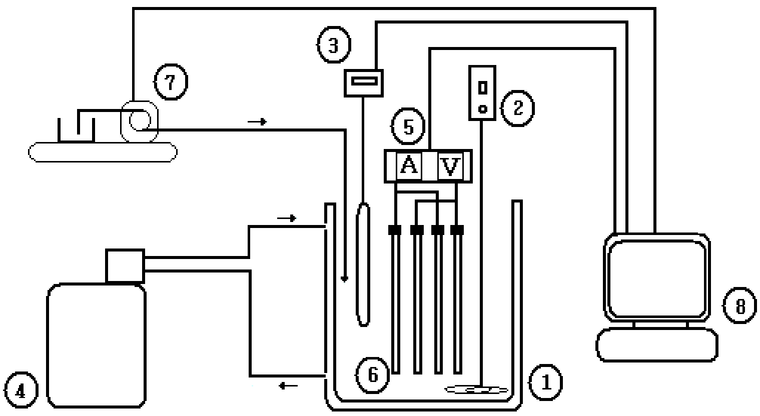



**Figure 2.** Schematic diagram of experimental setup

Figure 2 shows an electrolytic cell and the system equipment, 1: electrocoagulation reactor; 2: lab stirrer; 3: conductivity measurement device; 4: cooling water circulation bath; 5: constant current power supply; 6: Al electrodes; 7: NaCl solution pump; 8: computer.

As you can see in Figure 2, conductivity measurement is achieved by conductivity meter (3) and then the signal taken from this instrument is sent to computer (8) for realising computer control application. For PID control, manipulated variable is chosen concentrated NaCl solution. This solution is sent to the reactor by pump (7) controlled by a computer. PID control parameters are given to the computer and then with these parameters conductivity control is obtained. Electrocoagulation method has been realised with four electrodes (6) by using constant current power supply (5). Temperature control of this system is obtained by using on-off control method.

In each run, 1L of wastewater was placed into the electrolytic cell. Electrocoagulation is started with these four electrodes and then conductivity of the wastewater is changed with time and some properties of this wastewater are changed. In that case, control system is operated to get the conductivity at desired set point or the beginning value. The Matlab /Simulink programme which setup for conductivity control is shown in Figure 3. The PID algorithm was adapted to a Simulink programme.

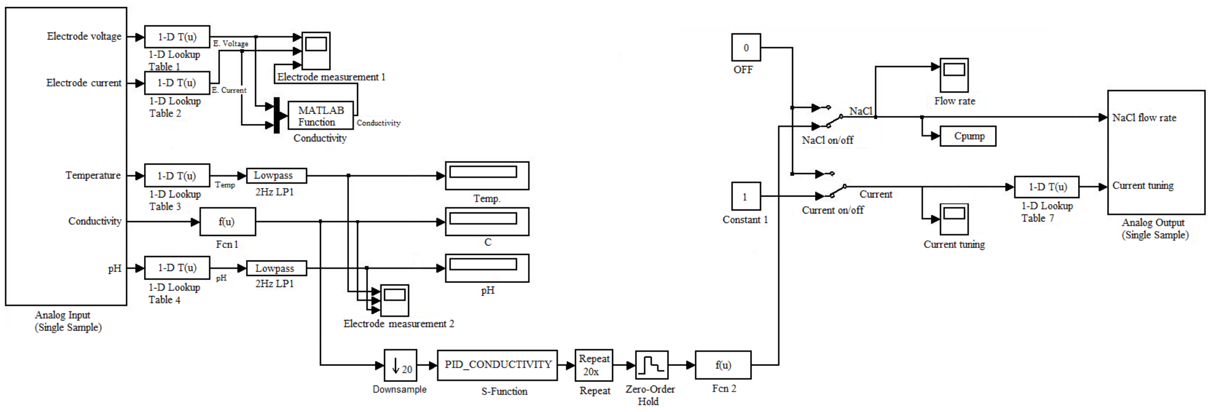
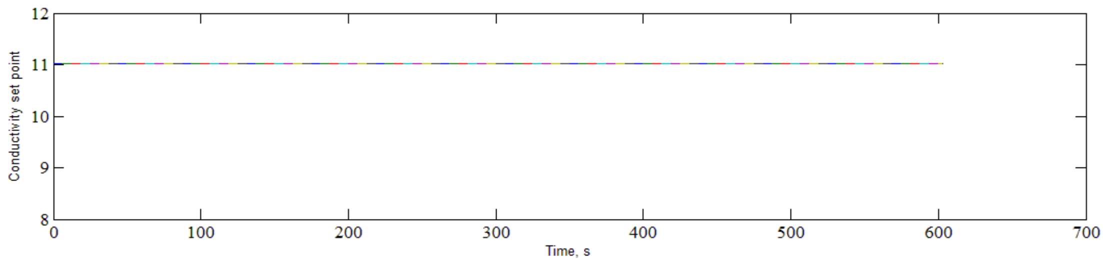



**Figure 3.** Matlab/Simulink plot diagram

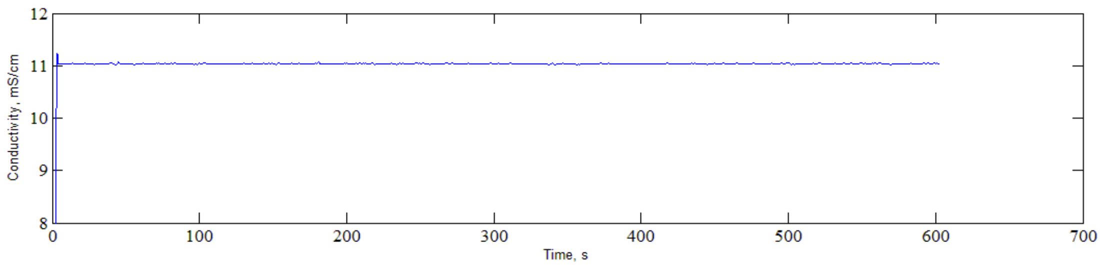
At the end of the experimental run, all samples were allowed to settle for 1 day in a vessel before any analysis. Neither centrifuging nor filtration was performed. The electrodes were washed thoroughly with distilled water to remove any solid residues on the surfaces. Colour and turbidity values were determined using a water analysis system (Orbeco-Hellige Model 975-MP).

## 3. Results and discussion

All the results from electrocoagulation treatment to wastewater taken from the textile industry are shown below. In this result PID control studies are given. Manual tuning has been used to define the proper PID parameters as explained before. This parameters has been found such as $K_C$ = 10, $\tau_D$ = 100 and $\tau_I$ = 5.




(a)




(b)

**Figure 4.** (a) The set point changing with time, (b) the conductivity of wastewater change with time

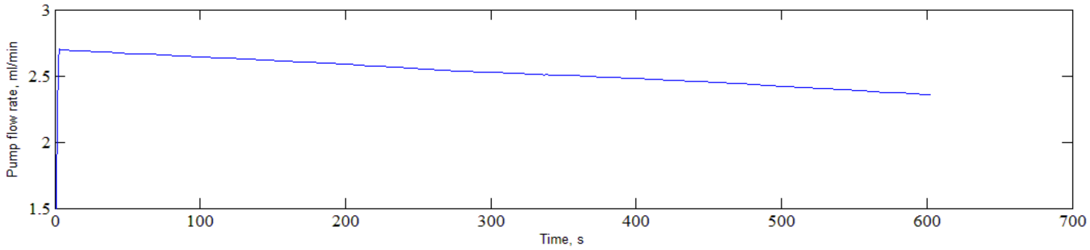



**Figure 5.** The manipulated variable changing with time during the electrocoagulation experiment

As it can be seen from Figure 4 electrocoagulation method has been studied and PID control is applied to this process and then very satisfactory result has been achieved. Conductivity measurements traced the set point during the reaction time. In Figure 5, manipulated variable has been shown and necessary NaCl solution is sent to the electrochemical cell to obtain the control sufficiently. NaCl solution flow rate has been used as a manipulated variable for PID control purpose. When conductivity measurement differs from set point, NaCl solution has been sent to adjust the conductivity value at its set point. Initially the NaCl solution pump flow rate is increasing to set the conductivity promptly at its set point. But high level of NaCl concentration goes to the system and as a result conductivity of the system is getting higher than the set point. In that time, the solution pump speed decreases to get the desired conductivity value.

**Table 1.** All the results from control studies

| Parameter | Units | Initial value | Final value | Removal efficiency |
|---|---|---|---|---|
| Conductivity | mS $cm^{-1}$ | 11.20 | 11.24 | - |
| pH | - | 6.74 | 7.42 | - |
| Temperature | °C | 21.19 | 23.71 | - |
| Turbidity | FTU | 594 | 39 | % 93.4 |
| Colour | CU | 1732 | 189 | % 89.1 |
| COD | mg $l^{-1}$ | 5720 | 340 | % 94 |

From Table 1 all the control studies results are shown. According to the same table, conductivity get constant during the control work, pH value is changing fairly. Temperature variation with time is 1.5 °C, this value is not effective very much for system properties. Control studies carry out in 1 hour efficiently, but in results and discussion section, 10 minutes for control studies is shown for clarity. For this reason, turbidity and colour measurements are shown in the same table for one hour control studies. And then these two results were taken from one hour control work. Satisfactory result for purification has been achieved.

## 4. Conclusions

Electrocoagulation method for purifying wastewater from textile industry has been studied. Studied wastewater from dyeing and finishing textile process, has a chemical oxygen demand (COD) concentration of 5720 mg $l^{-1}$ and a strong dark colour, is categorized as high strength wastewater. Removal efficiencies of COD was obtained as 94% for purification purposes with conductivity control case. As known that conductivity of wastewater changes with time during electrocoagulation treatment. Avoid this problem the table salt is usually employed to increase the conductivity of the wastewater to be treated. In this work, NaCl solution has been used to keep the conductivity of the wastewater as a constant or desired value. The signal communication is achieved between conductivity meter which measures the conductivity of the wastewater and computer, the conductivity signal is subtracted from conductivity set point and sends to the computer for PID control purposes. Matlab/Simulink programme is used to realise the PID studies. At the end, sufficient PID control has been achieved and very good purification for wastewater was obtained. In addition, power consumption for this process decreases by keeping conductivity of wastewater at the constant value. Without control in electrocoagulation process, conductivity of wastewater decreases and this causes increase in the power consumption. This means that the energy problem occurs in industry application (Chen, 2004).

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