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Research TEE

Process of Decolourisation of Textile Dye Using Electrocoagulation and Its Modelling Using Artificial Neural Network

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Abstract

Electrochemical technology encompasses a wide spectrum of technologies and makes numerous contributions towards a cleaner environment. In this work, the decolourization of the synthetic fabric dye solution containing CIBA (Company for Chemical Industry Basel) Red by electrocoagulation method has been investigated. Investigations have also been conducted on the impact of operational variables on colour removal effectiveness, including beginning pH, electrolysis duration, distance between electrodes. An electrode retention time, dye focus. She does and solves conductance. Neural computing is one of the fastest growing areas of artificial intelligence (AI). The use of AI in various environmental process control studies are of great importance as their predictions are quite difficult. To anticipate the process's productivity, an Artificial Neural Network (ANN) model was created that could produce accurate predictions about the electrocoagulation process's effectiveness.

Keywords: Electrocoagulation, artificial neural network (ANN), subject classification codes, environmental process control, electrochemical processes, artificial intelligence

INTRODUCTION

The great majority of people on the planet do not have access to clean water, which is one of the biggest problems confronting humanity today. In underdeveloped nations, there is an especially pressing demand for clean water. Aside from other anthropogenic activities, natural processes, and the careless discharge of industrial effluents, rivers, canals, estuaries, and other waterbodies are continuously being contaminated. Many nations have polluted ground water with substances like arsenic due to unknown geochemical processes. Due to a severe lack of useable water resources brought on by population growth, urbanisation, and climate change, highly developed nations also face an urgent need for wastewater cleaning. Wastewater treatment before discharge and wastewater reuse have become essential requirements. Therefore, the development of novel, cost-effective, and efficient wastewater treatment solutions is imperative.

WATER POLLUTION DUE TO COLOUR

The colour-related contamination of water is one of the most noticeable ones. The discharge of coloured industrial effluent is strictly prohibited and considered very objectionable due to its bad quality and numerous negative effects on the environment, particularly on the rivers that receive it. Excessive levels of colour in wastewater alter the receiving waters' visual appeal and hinder light penetration, which may have an impact on the habitat and growth of benthic plants. Furthermore, coloured

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effluents raise long-term BOD, raise the cost of water treatment for customers downstream of the discharge site, decrease river water photosynthetic activity, and increase toxicity. One common quantitative indicator of the level of pollution is the colour of the wastewater.

ELIMINATE COLOUR FROM WASTEWATER

Extensive research has been conducted on the most effective ways to eliminate colour from wastewater resulting from industrial and household activities. These consist of biological, chemical oxidation, membrane adsorption, cationic coagulation, polymer addition, ultra filtration, and activated carbon techniques. However, these physical, chemical, and biological colour removal techniques can often be ineffective, or even when they are, their high cost makes them expensive for the majority of enterprises. The electrochemical or electrocoagulation (EC) approach is widely recognised for its efficiency in eliminating colour from the majority of fluids and wastewaters. This method involves electrolyzing soluble anodes, often made of iron or aluminium, to produce metallic hydroxide flocs in the effluent.

In this work, decolourization of the synthetic dye solution containing CIBA (Company for Chemical Industry Basel) Red by electrocoagulation method has been investigated. Investigations have also been conducted on the impact of operational variables on colour elimination effectiveness, including beginning pH, electrolysis duration, and distance among electrodes. An electrode storage time, dye concentration, and solution resistivity.

The modelling of electrocoagulation was a very complex task, as the kinetic parameters involved in the various steps are difficult to determine. However, the development of neural computing and the use of artificial neural networks (ANN) made it feasible to simulate electrocoagulation even in the absence of a mathematical explanation of the numerous processes involved. Developing an artificial neural network (ANN) model capable of accurately predicting the electrocoagulation process's efficiency was a key goal.

Process Description of Electrocoagulation

Electrocoagulation is a process consisting of creating a floc of metallic hydroxides within the effluent to be cleaned, by electro-dissolution of soluble anodes. Metal ions generation takes place at the anode and the hydrogen gas is released from the cathode. The hydrogen gas would also help float the flocculated particles out of water. When a potential is applied from an external power source, the anode material undergoes oxidation, while the cathode will be subjected to reduction or reductive deposition of elemental metals [1, 2]. The most common electrode materials for Electrocoagulation are aluminium and iron.

Electrocoagulation in Treatment of Textile Dyes

Textile wastewaters are characterised by limited biodegradability, high pH and temperature, vivid colour, and high COD content. Due to their toxicity, dyes in wastewater induce biological and chemical changes, take up dissolved oxygen from streams, and kill aquatic life [3]. For this reason, textile effluents must be treated before being released into the receiving water. While a number of standard techniques, including adsorption, coagulation, flocculation, biological oxidation, and chemical oxidation, are frequently employed in the treatment of textile wastewater, they are not without their drawbacks. For instance, chemical coagulation generates a lot of sludge and causes additional pollution from unwanted reactions in treated water; adsorbents are typically difficult to regenerate; and biological methods are not appropriate for treating most textile wastewaters because some commercial dyes have negative effects on the organisms involved in the process. Furthermore, because of the wide variations in the composition of textile wastewaters, these traditional approaches are often costly and their treatment efficacy is insufficient [4]. The use of more recent dyestuffs, which are significantly more resistant to degradation, is making the issues more complicated. Because of its many advantages, such as its cost-effectiveness, energy efficiency, safety, selectivity, amenability to automation, and compliance with the environment, electrocoagulation (EC) is a popular process for treating textile dye. Cañizares *et al*. described this method as having simple equipment, being easy to operate, having a shorter reactive retention period, having little or no equipment for supplying chemicals, and producing less precipitate or sludge that settles quickly [5].

APPLICATION OF NEURAL NETWORK IN PROCESS MODELLING

Industrial process modelling and control have never been easy undertakings. The quest of novel technologies has been driven by the necessity of maintaining more stringent control over intricate and nonlinear systems. It follows that the recent years have seen a significant increase in interest in the field of neural networks.

The modelling of complex nonlinear processes, whose mechanisms are not well understood, is perhaps the most initially attractive application for neural networks. This is due to the fact that standard modelling methodologies are very labour-intensive, and it is generally understood that a lack of effective process models is a barrier to the dissemination of enhanced control [6]. It is challenging to develop a phenomenological model based on a chemical process, particularly when there is little information available about it. With a few benefits, neural networks may solve the modelling challenges: the possibility to apply it on complex non-linear processes, the ease in obtaining and using neural models, and the possibility to substitute experiments with predictions.

Application of Artificial Neural Network in Modelling Electrocoagulation

Due to the complexity of the reactions in the electrocoagulation systems, the kinetic parameters of the various steps involved are very difficult to determine, leading to uncertainties in the design and scale-up of chemical reactors of industrial interest. ANNs are a potential modelling tool that may be used to simulate the electrocoagulation process. Artificial neural network-based modelling has the advantage of not requiring a mathematical explanation of the processes involved, which makes it potentially helpful for upscaling and replicating intricate electrocoagulation systems. The selection of process variables, the amount of data that is accessible, and the domain that is utilised for training all have a significant role in the success of creating a dependable and resilient network [1].

THE EXPERIMENTAL SETUP AND PROCEDURE

Selection of Electrodes Material and Dye

In any electrochemical process, electrode material has significant effect on the treatment efficiency. Therefore, appropriate selection of the electrode material is important. The electrode material for treatment of water and wastewater should also be non-toxic to human health and environment. Iron and aluminium are the widely used electrode material because these are non-toxic and easily available [7, 4]. From the previous studies on textile dye removal efficiency using electrocoagulation done by Kobya *et al*. [4] and Bayramoglu *et al*. [7], it was found that iron electrode was more effective than aluminium electrode in treatment of textile wastewater. The possible reason for lower colour removal efficiency by aluminium in comparison with iron could be explained considering the insufficient ability of hydrous aluminium oxide to adsorb dye molecules. Also, some investigators have reported that the adsorption capacity of hydrous aluminium oxide for dye molecules is much lower than that of the hydrous ferric oxide [1]. Two numbers of metallic iron rods, each of 10 cm length and 1 cm diameter, were used as electrodes in the study. The commercial textile dye used in this study viz Cibacron Red FN-3G (CIBA, Switzerland); which is a fabric reactive dye. The main chemical constituent of Cibacron red dye is amino fluoro triazine.

Chemical Analysis

The dye was dissolved in distilled water to create the solution that contained the dye. Separate mixes were made for experiments with concentrations of dye in solution as 20, 40, 50, 75 and 100 mg/l. It was discovered that the colour removal effectiveness peaked at 50 mg/l. So, all other experiments were done at this concentration. The initial conductivity of dye solution was found to be 0.238 mS/cm and the initial pH was 7.6, which was later varied to study its effects on the colour removal efficiency. The conductivity of dye solution was varied by addition of NaCl. An electronic conductivity metre was used to evaluate the conductivity. A pH metre was used to monitor the dye solution's pH, and 1 N NaOH or 1 N H_2SO_4 solutions were added to modify the pH. The pH of the dye solution was measured with a digital pH metre.

The effect of various influencing parameters like, time of electrolysis, initial pH, initial dye concentration, initial conductivity, distance between the electrodes, and retention time, on the efficiency of colour removal were studied so as to design a predictive network. The American Public Health Association's recommended standard techniques were used to analyse any variables (APHA, 1995) [8].

METHODOLOGY

The electrocoagulation unit consisted of a 250 ml beaker which acted as the electrochemical reactor. Two numbers of iron rods of diameter 1 cm and length 10 cm was used as anode and cathode. The electrodes were connected to the respective anode and cathode lead of the DC rectifier, at a fixed current [9]. A full bridge rectifier was used to convert AC power supply to DC. A 230–24 V transformer was used to step down the AC power supply. The full bridge rectifier and the transformer together give an effective output DC voltage of 24√2 V. This supply was used throughout the experiment. Most of the studies on colour removal and textile waste treatment using electrocoagulation, used power supply around this value [7, 4, 10]. A voltage regulator and a generator were used to maintain a constant and uninterrupted power supply during electrocoagulation.

In each run, 250 ml of the dye solution was decanted into the electrolytic cell. All the runs were performed at room temperature. At the end of electrocoagulation process, all samples were allowed to settle for 5 min in the 250 ml vessel before any analysis. Then it was extracted and transferred to the spectrophotometric cell after filtering through a 0.2 µ filter paper for measurement of absorbance. A light-wave spectrophotometer (Genesys 20) was used throughout this study to measure the absorbance as shown in Figure 1. The maximum absorption (λ_{max}) wavelength of the dye was determined by measurement of their absorbance at various wavelengths. The λ_{max} of Ciba red dye solution was found as 485 nm, and all the analysis was done at this wavelength. The dye solution was prepared with varying concentrations in the range of 1 to 100 mg/l. The absorbance was measured using the spectrophotometer at each concentration and the calibration curve was plotted. The calculation of colour removal efficiency after electrocoagulation treatment was performed. The following equation was used to calculate the colour removal efficiency of the treatment:

$$R\%=\{(C_0-C)/C_0\}\times100$$

Where C_0 and C were the initial and present concentrations of the dye in solution (mg/l), respectively [1].

To find the optimum condition for each of the variable analysed, the electrocoagulation process was carried out by varying the parameter under consideration and keeping other parameters constant. To find the optimum time of electrolysis, the concentration of the solution was kept as 50 mg/l, distance between the electrodes as 5 cm, conductivity of the solution as 0.238 mS/cm, pH of the solution 7.6 and the retention time of the solution after electrocoagulation as 5 min.

When the concentration of the dye solution was made the variable, the time of electrolysis was 90 min, distance between electrodes 5 cm, conductivity 0.238 mS/cm, pH 7.6, and retention time 5 min. To find the optimum distance between electrodes, the time of electrolysis was 90 min, concentration of the dye solution 50 mg/l, conductivity of the solution 0.238 mS/cm, pH of the solution 7.6 and the retention time after electrocoagulation 5 min.

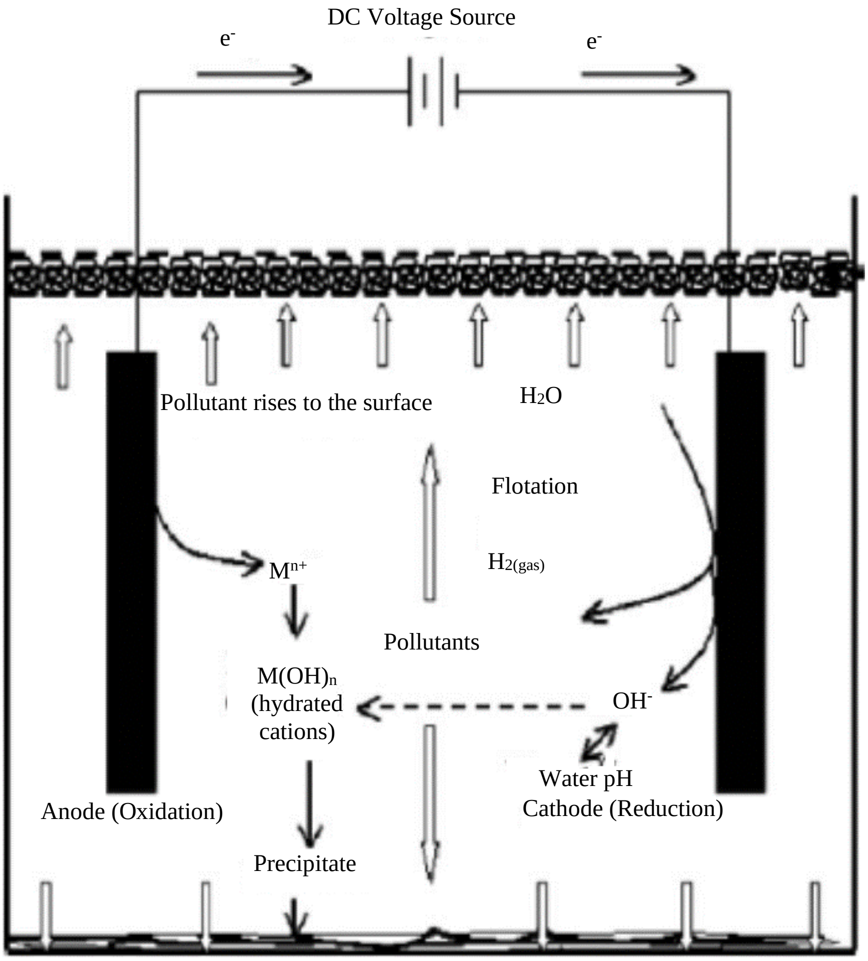

Figure 1. Schematic representation of electrocoagulation apparatus.

To find the optimum conductivity of the solution, the time of electrolysis was 90 min, concentration of the dye solution 50 mg/l, distance between electrodes 5 cm, pH of the solution 7.6 and the retention time of the solution after electrocoagulation 5 min. To find the optimum pH, time of electrolysis was 90 min, concentration of solution 50 mg/l, distance between the electrodes 5 cm, conductivity 0.238 mS/cm, and a retention time of 5 min. Optimum retention time was found by keeping, the time of electrolysis 90 min, concentration of the dye 50 mg/l, distance between electrodes 5 cm, conductivity of the solution 0.238 mS/cm, and pH of the solution 7.6.

Training of Neural Network Using Matlab

All ANN calculations were carried out using Matlab mathematical software with ANN toolbox for windows running on a personal computer. As seen in Figure 2, the neural net (multilayered perceptron) is a parallel linked structure made up of three layers:

1. An output layer (dependent variables),
2. Several hidden layers, and
3. An input layer of neurons (independent variables).

The number of input and output neurons required depends on the nature of the problem. Feature detectors are the hidden layers. There could be more than one concealed layer. However, according to universal approximation theory, every input-output structure may be understood by a network consisting of a single hidden layer and a sizable enough number of neurons. Thus, a single hidden layer of six neurons was employed in this work.

The design of an artificial neural network (ANN) is influenced by the total number of layers, the quantity of nodes within each layer, and the type of function that transfers information. First, while creating an ANN model for a process, the collection of independent input variables and the output variables must be correctly identified. Most likely, the next crucial stage in the creation of a model is the optimisation of ANN topology. The present research utilised a three-layered feed forward backward propagation neural network (6:6:1) to explain the mechanism of electrocoagulation (Figure 2).

The electrolysis duration (min), starting pH, initial dye concentration (mg/l), conductivity (mS/cm), sludge retention time (min), and distance between electrodes were the input variables fed into the feed forward neural network. An experimental data sets of 30 data set was used to develop the ANN model. The range of variables studied is summarized in Table 1.

Table 1. Model Variables, and their ranges of variation.

Variables	Range
Input layer	
Time of electrolysis	30–120 min
Initial dye Concentration	20–100 mg/l
Distance between the electrodes	2–7 cm
Conductivity	0.238–8.16 mS/cm
Initial pH	3–10
Retention time of sludge	5–65 minutes
Output Layer	
Colour Removal Percent	0–100%

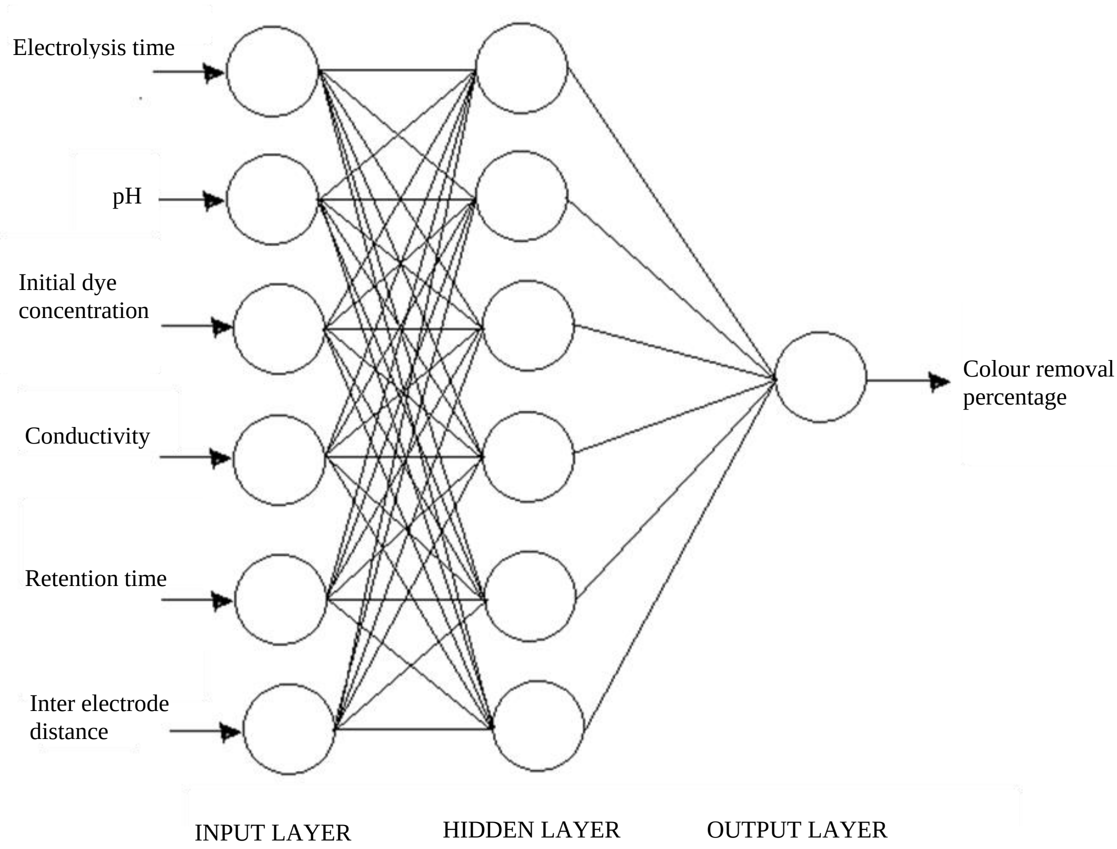

Figure 2. The ANN Structure.

EFFECT OF VARIOUS PARAMETERS

Effect of Initial Dye Concentration

The dye solution with different initial dye concentrations in the range of 20–100 mg/l was treated by electrocoagulation. The colour removal efficiency was plotted against initial dye concentration (Figure 3). The colour removal efficiency decreased with an increase in dye concentration. The presumed reason is deducible from Faraday's law.

$$\Delta M = \frac{MIt_{\mathrm{EC}}}{nF}$$

Where ΔM is the amount of iron dissolution, which will produce the corresponding hydroxide floc (g); M the molecular weight of the iron (g/mol); n the number of electron moles; and F is the Faraday constant (F=96,487 C/mol).

According to Faraday's law, a constant amount of Fe^{2+} is passed to the solution at the same current density and time for all dye concentrations [11]. Consequently, the same number of flocs would be produced in all the solutions. As a result, the flocs produced at high dye concentration were insufficient to adsorb all of the dye molecules of the solution.

Up to the concentration of 75 mg/l, the adsorption capacity of flocs was not exhausted, and the rate of colour removal was relatively constant. However, beyond this concentration, the adsorption capacity of flocs became exhausted, and the removal efficiency began to drop. The optimum efficiency was found at a concentration of 50 mg/l.

Effect of Time of Electrolysis

During electrolysis, the released ions due to anodic and cathodic reactions neutralize the particle charges and thereby initiate coagulation. The colour removal efficiency depends directly on the concentration of ions produced by the electrodes. When the electrolysis period increases, the concentration of ions and their hydroxide flocs increases [1]. Accordingly, as shown in Figure 4, an increase in the time of electrolysis from 30 to 120 min yields an increase in the colour removal efficiency from 10.84 to 97.13%. The colour removal became almost constant after 80 min. A very slight decrease in efficiency after 75 min may probably be due to the dye molecules desorption from flocs to solution [11].

Effect of Initial pH

The pH of the solution has a major impact on the procedure known as electrocoagulation. Sodium hydroxide or sulfuric acid were added to the dye solutions to bring them to the appropriate pH for each experiment to test its impact. The effectiveness of colour removal, as a function of pH, is shown in Figure 5. The initial pH has a significant effect on the colour removal efficiency, especially at low pH. It is clearly indicated that the colour removal efficiency increased with pH, with the peak value between pH 6 and 8. Then on further increase of pH, the colour removal efficiency decreased. Lower percentage removal was observed at the pH<6. This is due to insufficient amount of iron hydroxide complexes formed at lower pH. At pH>8, colour removal efficiency decreased very sharply, because above this pH, $Fe(OH)^{4-}$ is the dominant species. $Fe(OH)^{4-}$ gets dissolved and is unable to form flocs. The optimum pH was found to be 7.6 with a removal efficiency of 96.88%.

Effect of the Conductivity

Due to the chemical substances added at a high concentration from dyeing and finishing processes in the textile industry, the textile wastewaters have a broad variation in ionic strength. Therefore, it is highly necessary to investigate the effect of conductivity on electrocoagulation in terms of colour removal. The conductivity of the solution was adjusted to the desired levels by adding NaCl in increments of 1 mg to the 250 ml solution used for analysis. The effect of NaCl concentration or conductivity on removal efficiency is shown in Figure 6. The optimum colour removal efficiency was

96.88% at 0.238 mS/cm. The colour removal efficiency was found to show only a slight variation after that. It appeared that conductivity had little effect on colour removal efficiencies in the investigated range of 0.238–8.16 mS/cm. However, slight decrease in the decolourization efficiency may be attributed to a change in the ionic strength. Ionic strength affects the kinetics and equilibria of reaction between charged species occurring due to electrocoagulation [12].

Effect of Distance Between the Electrodes

The variation of colour removal efficiency for electrode distances are presented in Figure 7. The maximum efficiency of colour removal was observed at interelectrode distance 5 cm. The optimum removal efficiency was found to be 96.88%. This is because when the distance is increased, the resulting movement of the ions is slower and there is greater opportunity for the ions to aggregate and produce flocs to adsorb the dye molecules [13]. Increase in the distance between the electrodes causes ohmic losses (Raju et al.,[9]). As a result, the optimal distance between the anode and the cathode for all the experiment was set at 5 cm.

Effect of Retention Time on the Removal Efficiency

Once the electrolysis process was performed, the samples were kept for settling of the floc formed. When retention time is increased from 5 to 65 min, the removal efficiency showed very slight variation ranging between 96.88 and 98.41%. So, a retention time of 5 min was adopted in all other analyses as a considerable variation was not observed by increasing the retention time. Figure 8 shows this variation.

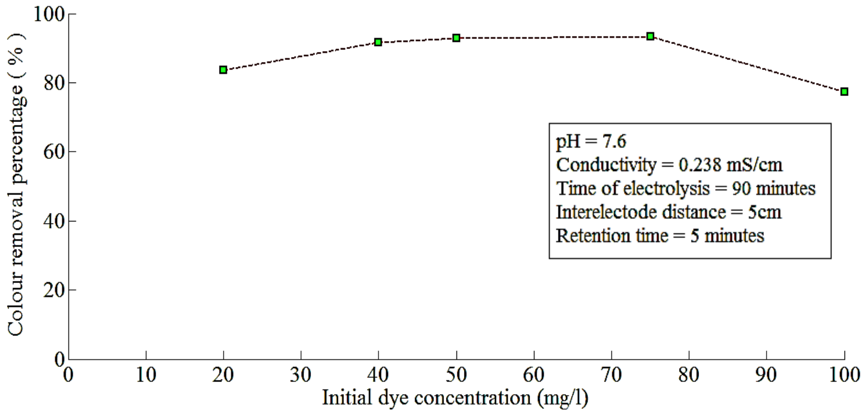

Figure 3. Effect of initial concentration on the colour removal efficiency.

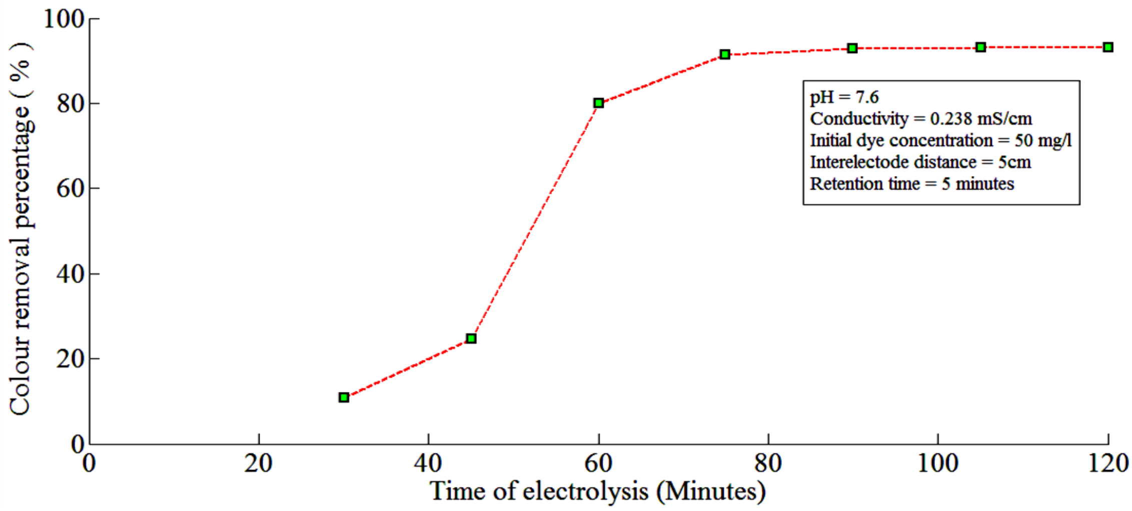

Figure 4. Effect of time of electrolysis on the colour removal efficiency.

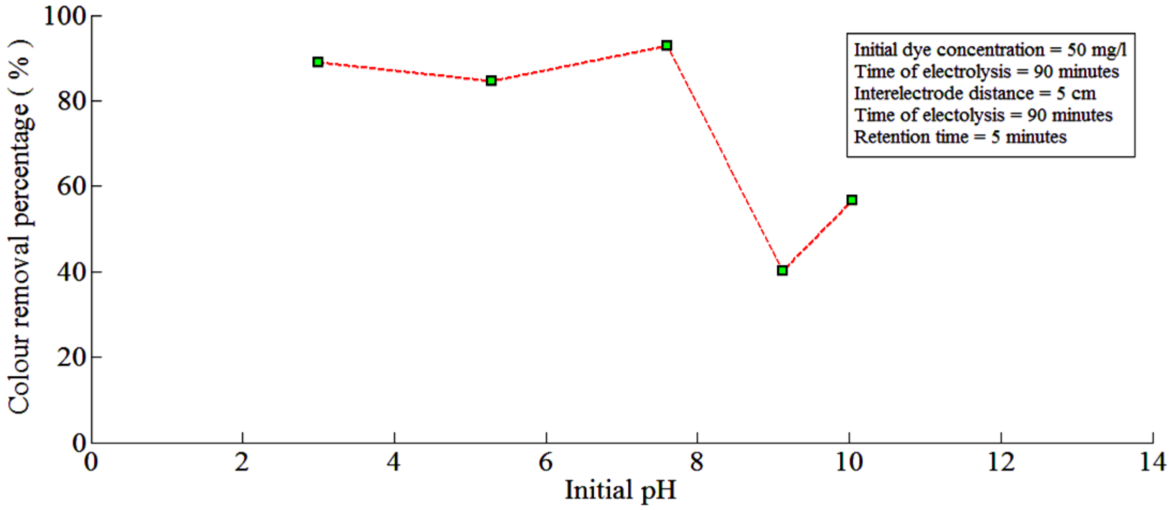

Figure 5. Effect of initial pH on the colour removal efficiency.

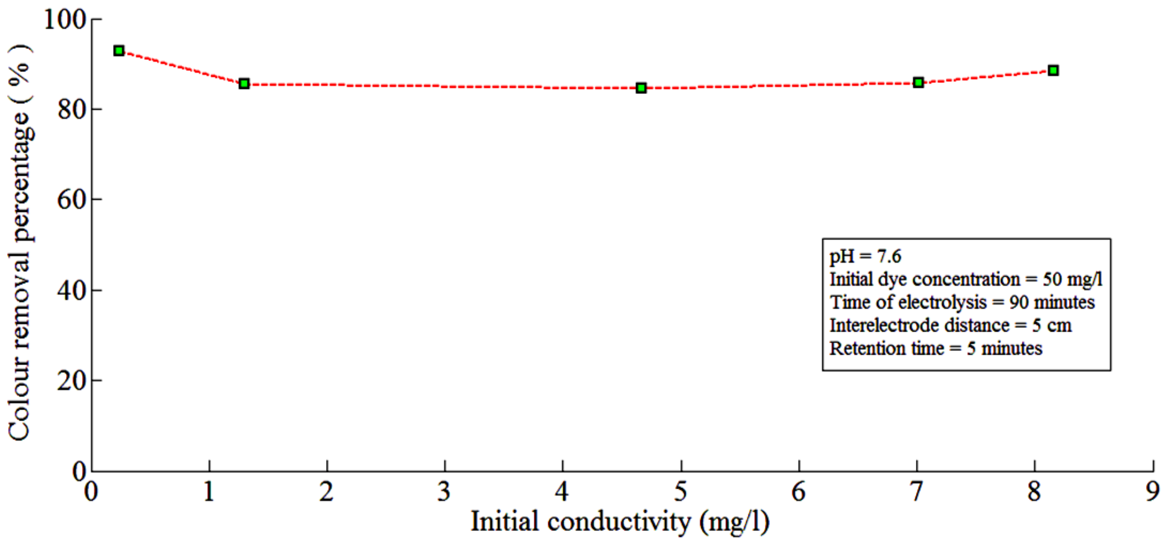

Figure 6. Effect of initial conductivity on the colour removal efficiency.

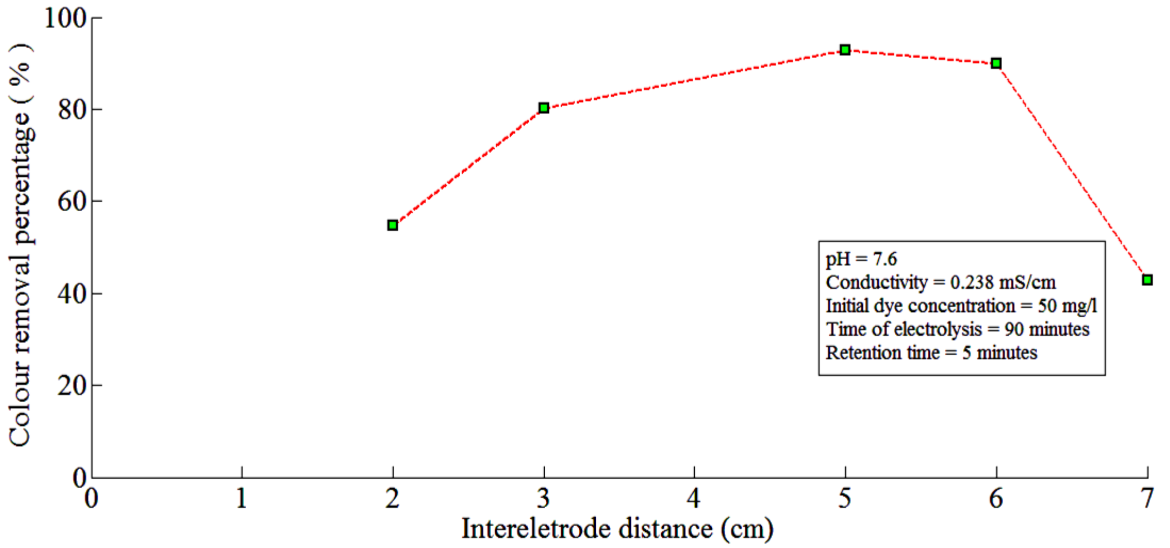

Figure 7. Effect of inter electrode distance on the colour removal efficiency.

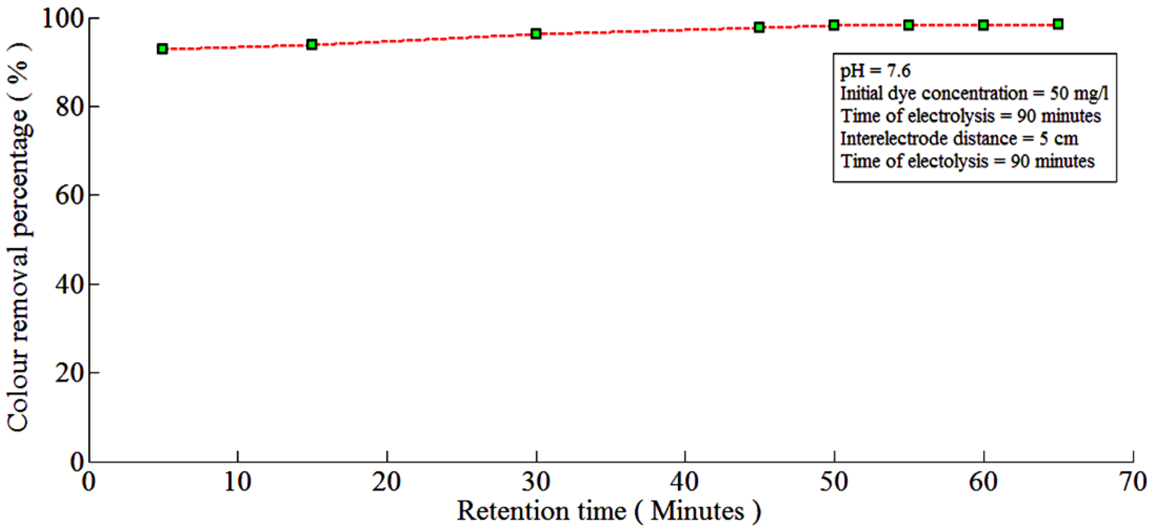

Figure 8. Effect of retention time on the colour removal efficiency.

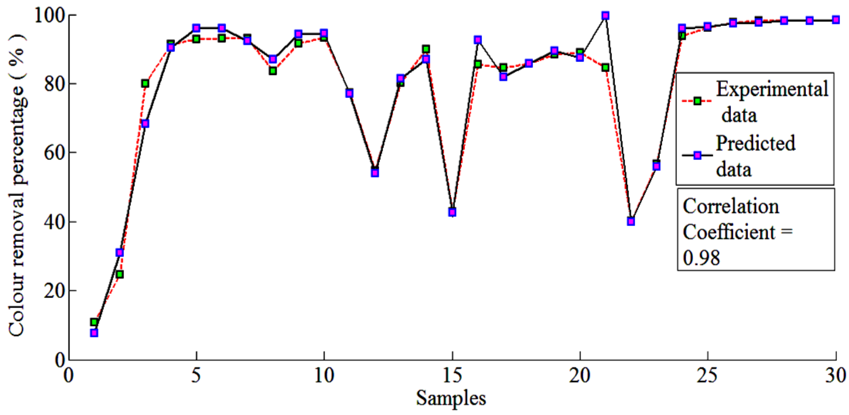

Figure 9. Comparison of ANN predicted and experimental values of colour removal efficiency.

ANN Modelling

Artificial neural network (ANN) model was developed using the Matlab software. The variation in colour removal efficiency between the estimated and experimented data is shown in Figure 9. A good agreement between the estimated and experimental data in both the diagrams confirms the validity of the methodology developed. The correlation coefficient, R^2 of the estimated and experimented data from this study was found to be 0.9813. The result confirms that the neural network model effectively reproduces the decolorization of the system, within the experimental ranges adopted in the model fitting. A predictive network which can be used for any arbitrary inputs within the limits specified was also developed.

CONCLUSION AND SCOPE FOR FURTHER STUDIES

One of the best methods for getting colour out of wastewater from textile dyes is electrocoagulation. In this work, the electrocoagulation method, which removed colour from a dye solution containing Cibacron red, was shown to be quite successful. A good removal rate was achieved with the iron electrode. The impact of diverse operational parameters on the efficacy of colour removal was examined and refined. It has been successful to examine the cause-and-effect relationship in the electrocoagulation process through the application of artificial neural network modelling. Under the variety of experimental settings used, the behaviour of the complicated chemical system could be explained by the ANN model. An ANN-based simulation model can be used to estimate how the system would behave in various scenarios. Scope for further studies include, on various other parameters, using solar power or alternatives to reduce power consumption, possible recovery of dye and scope of water reuse.

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