Removal of Alizarin Red S dye from aqueous solution by electrocoagulation process

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Abstract: In this study, removal of Alizarin Red S (ARS) dye from aqueous solution using electrocoagulation (EC) process has been investigated. The process was carried out in a batch electrochemical cell with aluminium electrodes in a monopolar connection with aqueous solution of ARS dye. The removal of dye from the aqueous solution depends on various parameters influencing the electrocoagulation process. Therefore, it was necessary to study the effect of various parameters of the electrocoagulation process. The parameters taken for the experimental investigation are initial concentration, current intensity; electrolyte concentration and inter-electrode distance. The initial pH of the process was maintained at 7. In this work, the following range of the parameters are taken: for initial concentration 5 – 35 ppm, for current intensity 2-5 Ampere (A), for electrolyte concentration 4-20ppm and for inter-electrode distance 0.6-2.4cm. It was observed that increase in removal of ARS dye (93.5%) was obtained with decrease of initial concentration of dye (5ppm). Similar removal of ARS dye (97%) was found with increase in current intensity (5A). However, with the increase in electrolyte concentration the removal percentage increased from 76.77% to 79.89% which is almost negligible. The removal percentage of ARS decreased from 95.5% to 69.77% with inter electrode distance from 0.6 cm to 2.4cm.

Keywords: Electrocoagulation, aluminum electrodes, Alizarin Red S, current intensity, electrolyte

I. INTRODUCTION

One of the additional demanding challenges within the 21st century is that the facility of sufficient clean water system which is free from pollutants. Therefore, it's not appalling that there is a rising interest in emerging new machineries that are conventional, low-cost and enormously economical in the removal of pollutants from waste water [1]. India is one of the chief clothing and fabric commerce country within the world. It is one of the high pollution manufacturing industries due to the usage of dyes [2]. Dyes like Alizarin Red S (ARS) and significant metals like iron, mercury, metal etc. are the key pollutants. As this trade progressed an immense variety of waste product was discharged into the surroundings that increased the threat to each human and aquatic life. ARS is a metal salt of 1, 2-dihydroxy-9, 10-an-thraquinonesulfonic acid that is soluble in water and is employed in printing, coloring purpose [3]. It consists of complicated aromatic rings that makes it optically stable, thermal and extremely physcio chemical and since of that it's not biologically or physiochemical degradable. It's a typical salt of anthraquinone that belongs to the cluster of most sturdy pollutants. So it's necessary to get rid of ARS in a good ways which are economically and environmentally possible. Electrocoagulation has been recommended as a substitute to chemical curdling within the treatment of wastewaters. During this technology, metal cations are freed into the water by dissolving metal electrodes. The electrocoagulation method takes place in a chemistry cell. Consequently, its potency performance is directly associated with the operational state of the electrodes. Additionally, the selection of the current has a crucial impact on the energy used within the method.

It is based on in-situ electrolytic dissolution of the anode metal material and should be promptly machine-controlled. At the anodal reaction, gas bubbles are generated at the cathode surface, promoting electro-flotation. Usually, Al, Fe, and/or stainless steel are used as the electrode materials. The prevalence of those metals (Al, Fe) is due to their accessibility, cheap worth, non-toxicity, and proved effectiveness [4]. Other metals, such as Mg, have additionally been used sometimes [5]. Inert aerated cathodes (air cathodes) may be used [6]. EC process can be carried out with either one or multiple anode-cathode pairs, and may be connected in serial or parallel, in either a monopolar or a bipolar mode [7]. The main reactions occurring in the Aluminum Electrodes are as follows [8]:

Anode:

$$Al \rightarrow Al_3^{+} + 3e^{-}$$

Cathode:

$$2H_2O + 2e^{-} \rightarrow H_2 + 2OH^{-}$$

According to various studies, evolution of oxygen occurs along with secondary reactions when the potential of the anode is significantly high [9].

$$2H_2O \rightarrow O_2 + 4H+ + 4e-$$

The Aluminum ions (Al_3^{+}) which have already been produced by electrochemical reaction, dissolves in the solution and undergoes instant hydrolysis reactions, generating many monomeric species. They are as follows:

$$Al_3^{+} + H_2O \rightarrow Al(OH)_2+ + H^{+}$$

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 DOI : 10.18231/2454-9150.2018.0495

$$Al(OH)_2^+ + H_2O \rightarrow Al(OH)_3 + H^+$$

The Aluminum ions can also form polymeric species like dimeric and trimeric by hydrolysis. The polynuclear hydrolysis products are: $Al_2(OH)_{24}^+$, $Al_3(OH)_{45}^+$, $Al_6(OH)_{153}^+$, $Al_7(OH)_{174}^+$, $Al_8(OH)_{204}^+$, $Al_{13}O_4(OH)_{247}^+$, $Al_{13}(OH)_{345}^+$ [10]. The regions close to anode becomes acidic due to hydrolysis reactions. On the other hand, the cathode region is alkaline in nature due to hydrogen evolution. The aluminium reacts with OH^- ions and change to amorphous solid $Al(OH)_3$ by precipitation kinetics in the bulk solution [11]. The pH and the coagulant dosage have a strong effect on the mechanisms of the coagulation process. In the present work, removal of Alizarin Red S (ARS) dye from aqueous solution using electrocoagulation (EC) process has been investigated. The process was carried out in a batch mode. An electrochemical cell with aluminium electrodes in a mono polar connection with aqueous solution of dye was used. The pH of the process was maintained at 7. The effect of various process parameters of the electrocoagulation process such as initial concentration of ARS dye, current intensity; electrolyte concentration and inter-electrode distance were evaluated. The study of the effect of parameters on EC is necessary for the modeling of EC reactor.

II. MATERIALS AND METHODS

A. Chemicals Required

Alizarin Red S was procured from Merck, India. NaOH and H_2SO_4 were used to maintain the pH of the solution also procured from Merck, India. NaCl was used as the electrolyte purchased from Merck, India Double distilled water was used to prepare the various solutions of dye. Aluminum electrodes of ~98% purity were procured from local market.

B. Procedure of the experiments

A 2L capacity of beaker was utilized for this purpose. For each of the experiment 1L of aqueous dye solution was taken. A pair of aluminium plate of dimension 100mm × 30mm × 1.5mm were used as both the anode and cathode. It was then screwed against the perplex rod and submerged into the aqueous dye solution. The submerged surface area of each electrode was 0.004 m^2. Figure 1 shows a schematic representation of the process. Distances between the electrodes were varied from 0.6 to 1.8 cm as per experimental requirement. The anode and cathode were connected to a digital DC power supply (Make: Aplab). In addition to this, a digital ammeter was also connected to the circuit to check the current intensity. EC unit was place on a magnetic stirrer (Make: Remi) and it was then stirred using a magnetic bar at constant speed. All the experiments were performed at the room temperature (25±°C). The color of the dye changes with different pH (Figure 2). After the electrocoagulation process is conducted the color obtained was near to 7 pH. Thus, the initial pH was maintained at 7.0±0.1 by using 0.1M solution of H_2SO_4 and NaOH. The conductivity of the solution was maintained by using the desired amount of NaCl.

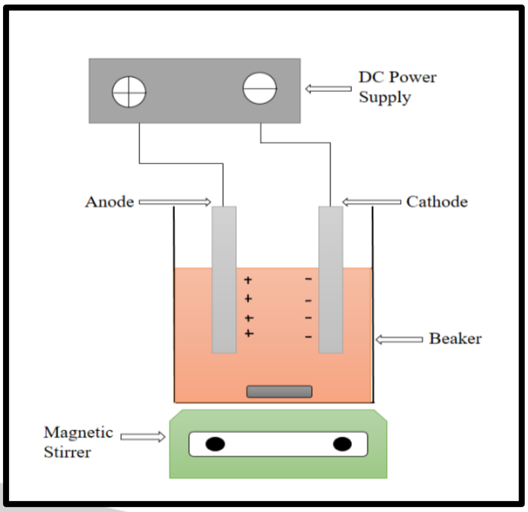

Figure 1: Schematic representation of monopolar electrocoagulation process

Figure 2: Different colors of Alizarin Red S dye at different pH

Before each experiments the conductivity, pH, temperature and salinity was measured and monitored during the experiment by pH meter. All the experiments were performed for a fixed period of time of 40 minutes. The decanted sample was filtered through Wattman filter paper. The filtered aqueous solution was then collected and analyzed in a UV Spectrophotometer (Make: Perkin Elmer, Model: D2000, λ_{max} = 460 nm) to obtain the percentage of removal of dye. The percentage of removal of dye was calculated by using the following equation:

$$Removal\,\% = \frac{C_i - C_f}{C_i} * 100$$

where C_i and C_f are the initial and final concentration of ARS solution, respectively.

III. RESULTS AND DISCUSSION

A. Effect of different parameters on electrocoagulation

In this section, the effect of various parameters of the EC process using monopolar electrode connection were discussed. The parameters such as initial concentration, current intensity, electrolyte concentration and Inter-electrode distance were investigated.

B. Effect of initial concentration on the removal of ARS

The effect of initial concentration on the removal of ARS with current intensity: 3A, inter electrode distance: 1.2cm, electrolyte concentration: 10ppm is shown in Figure 2. To observe the result of initial dye concentration on the dye

 DOI : 10.18231/2454-9150.2018.0495

removal potency by EC, experiments were administrated for four totally different dye concentrations (5, 15, 25 and 35 mg/ L) for 40 min with constant current intensity of 3 A . It can be seen from the figure that the dye removal potency decreased with the increase in initial dye concentration. For 40 minute of operation, dye removal decreases from 93.5% to 76.77% once dye concentration was amplified from 5 to 35 mg/L. It has been due to the fact that at constant current density and time, an equivalent quantity of hydrated aluminium oxide complexes was generated for all the dye solutions. Consequently, an equivalent quantity of flocs was made within the solutions. As a result, the flocs made at high dye concentration were too little to take up all of the dye molecules of the process [12]. For low concentration of dyes, the amount of hydrated aluminium oxide complexes was higher compared to the amount of dye molecules [13]. Hence 93.5% dye removal was obtained in compared to higher concentration. Hence, it was quite clear that beneath this in operation conditions, the lower is that the dye concentration higher would be the removal percentage. Similar results were reported elsewhere for the removal of reactive dye solutions by EC method [14].

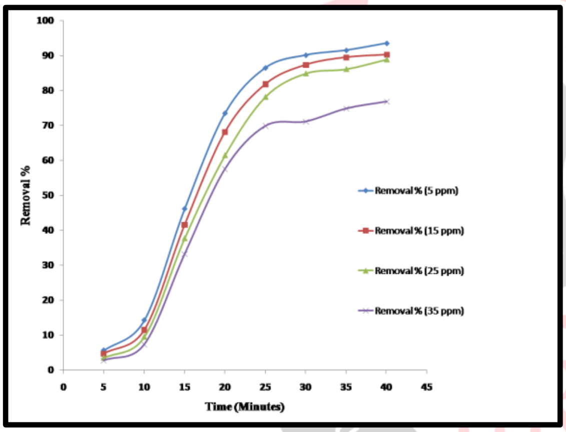

Figure 3: Effect of Initial Concentration of dye on the removal of ARS with current intensity: 3A, inter electrode distance: 1.2cm, electrolyte concentration: 10ppm.

C. Effect of current intensity on the removal of ARS

Current intensity is one of important parameter in EC process. Effect of current intensity on the removal of ARS with initial concentration of ARS: 15ppm, inter electrode distance: 1.2cm, electrolyte concentration: 10ppm is shown in Figure 4. Increase in current intensity increases the removal percentage of ARS can be witnessed from Figure 4. To study the effect of current intensity, experiments were carried out at different current intensity ranging from 2-5A keeping all other parameters consatnt. At 2A current intensity the removal % was 79.77 and whereas, at 5A it was observed as 97%. The current and the time of electrocoagulation determine the amount of coagulants that have been formed. The amount of current passed in the system helps in adjusting the rate of coagulant production and also the size of the bubbles [15]. It also affects the growth of flocs. Increasing current density results in a corresponding increase in the production of coagulant in the solution leading to high efficiency [16].

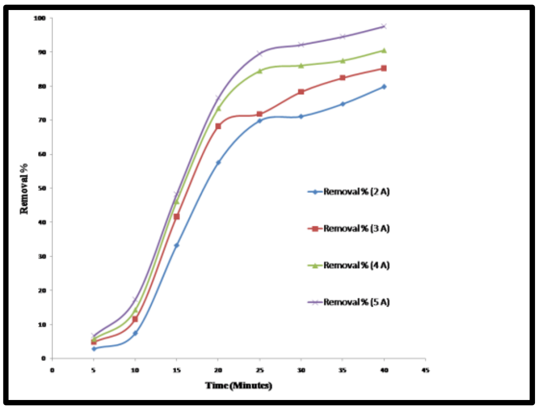

Figure 4: Effect of current intensity on the removal of ARS with initial concentration of ARS: 15ppm, inter electrode distance: 1.2cm, electrolyte concentration: 10ppm.

D. Effect of electrolyte concentration on the removal of ARS

Effect of electrolyte concentration (NaCl) on the removal of ARS with initial concentration of ARS: 15ppm, inter electrode distance: 1.2cm, current intensity: 3A shown in Figure 5. NaCl is typically used to extend the conductivity of the solution to be treated by EC. Experiments were performed using different concentrations of NaCl (4-20 mg/L). From the figure, it can be seen that with a rise in electrolyte concentration, there was hardly any improvement in removal of ARS from the aqueous solution with time. In another word, raising the electrolyte concentration has no substantial development on the dye removal. This phenomenon was also seen in the previous literatures [17, 18]. With the increase in NaCl concentration the removal percentage increased from 76.77% to 79.89% which is almost negligible. Increase in NaCl concentration decreases the cell voltage at constant current density and thus, reduces the power consumption in electrolytic cells [19]. Increase in NaCl concentration, will increase the ion concentration within the solution and thus reduces the resistance between the electrodes [20-22].

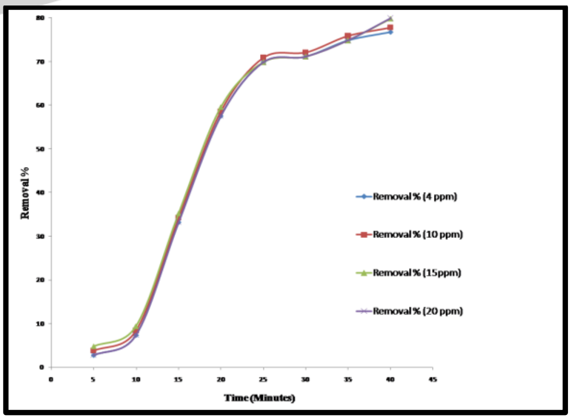

Figure 5: Effect of electrolyte concentration on the removal of ARS with initial concentration of ARS: 15ppm, inter electrode distance: 1.2cm, current intensity: 3A.

E. Effect of inter electrode distance on the removal of ARS

 DOI : 10.18231/2454-9150.2018.0495

To study the effect of inter electrode distance on the removal of ARS, experiments were carried out using 0.6-2.4cm electrode distance taking initial concentration of ARS: 15ppm, electrolyte concentration: 10ppm, current intensity: 3A and is shown in Figure 6. From Figure 6 it is evident that the removal % decreases with increase in inter electrode distance. The value decreased from 95.5% to 69.77% while the inter electrode distance increased from 0.6 cm to 2.4 cm. This is due to the fact that as the inter electrode distance increased the resistance between also increased leading to low mass transfer between the solid and fluid particles [23]. Similar reports is also supported by the other studies, as the inter-electrode distance increases, the system voltage and the resistance increases [24]. Therefore, by applying a suitable inter-electrode distance, the operating cost and power consumption could be decreased. The inter-electrode distance also affects the current density distribution [25-26].

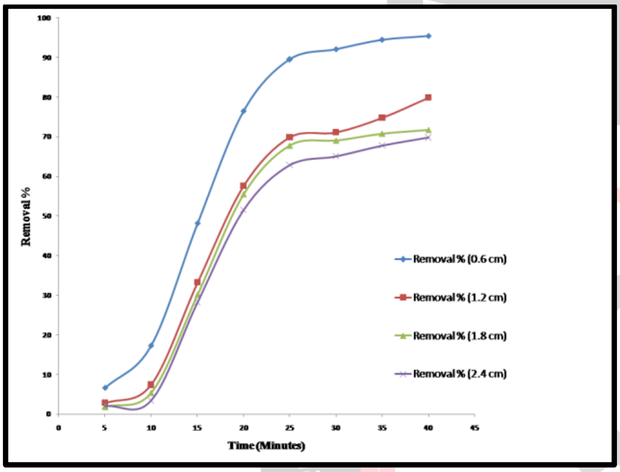

Figure 6: Effect of inter-electrode distance on the removal of ARS with initial concentration of ARS: 15ppm, electrolyte concentration: 10ppm, current intensity: 3A.

IV. CONCLUSION

Detailed investigation has been carried out in this study regarding the effect of various parameters on removal of Alizarin red S using monopolar electrocoagulation process. The effect of various parameters of the electrocoagulation process, such as initial concentration, current intensity; electrolyte concentration and inter-electrode distance were evaluated. There was an increase in the removal percentage of Alizarin Red S with the increase in current intensity and decrease in removal percentage with increase in initial concentration of dye and inter electrode distance. However, change in electrolyte concentration has not much effect on the removal percentage of the dye from the aqueous solution as it increases the conductivity of the solution, thereby, reduces the power consumption. It was observed that increase in removal of ARS dye (93.5%) was obtained with decrease of initial concentration of dye (5ppm). Similar removal of ARS dye (97%) was found with increase in current intensity (5A). However, with the increase in electrolyte concentration the removal percentage increased from 76.77% to 79.89% which is almost negligible. The removal percentage of ARS decreased from 95.5% to 69.77% with inter electrode distance from 0.6 cm to 2.4cm. The results obtained from this study will be utilized in modeling of EC reactor and further scaling up of the system.

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 DOI : 10.18231/2454-9150.2018.0495