Continuous flow electrocoagulation system for the treatment of coir industry wastewater

Ayyappan.U.[1,2*], Indu M.S[1], Adithya. G. Murickan[1], Balagopal J.[1], Arun S Kumar[1], Priya K L[1]

[1]Department of Civil Engineering, TKM College of Engineering, Kollam, Kerala, India
[2]School of infrastructure, Indian Institute of Technology, Bhubaneswar, India

*Corresponding author: merclogyk@gmail.com

ABSTRACT

Coir industry, a prominent industry in Kerala, uses huge amount of water and chemical reagents for its functioning. The effluent from these industries has high BOD, COD, toxic chemicals, oils and grease etc. Of the various pollutants, synthetic dyes are the most concerning. Electrocoagulation has advantages over other systems, as it doesn't produce any secondary pollutants. In this study, a continuous flow electrocoagulation reactor is designed and operational parameters like flow rate, voltage, pH, electrolyte concentration, dye concentration and electrode orientation are optimized. The influence of these parameters are assessed by measuring colour removal efficiency (CRE) and chemical oxygen demand (COD). The optimum flow, voltage, electrolyte concentration, pH and electrode orientation were 1000 mL/hr., 8V, 1000 mg/L, 7 and parallel respectively. The optimized parameters were used for performance evaluation of the system in treating coir industry wastewater. Under these optimized conditions, colour removal efficiency, turbidity, pH, COD removal efficiency and BOD removal efficiency for the treated coir industry wastewater was found as 92.17%, 25 NTU, 8.7, 95.49%, and 92.20% respectively.

Keywords: Electrocoagulation, Dyes, Optimization, Colour removal efficiency, COD removal efficiency.

1 Introduction

The coir and textile industries consume a large amount of water and chemicals for wet processing of fibre. Synthetic dyes are used to colour the processed coir to make carpets, mats, ropes etc. The effluent from the industry contains chemicals like dyes and pigments, glucose, alcohol, fatty acids, acetic acid, soaps, detergents, chlorides, phenols, peroxides etc. and are coloured, high in BOD, COD, oils and grease. Out of these chemicals, dyes are the most important pollutant since it affects not only the aquatic flora and fauna but also cause serious harmful changes in the entire food web. Dyes absorb light with wavelengths in the visible range, i.e. 350 to 700 nm. Due to the toxicity, mutagenicity and carcinogenicity of synthetic dyes and their breakdown products, their removal from industrial wastewaters is an urgent challenge. Dyes are major sources of heavy metals like; Cd, Cr, Co, Cu, Hg, Ni, Mg, Fe and Mn. These pollutants destroy microorganisms that lead to a reduction in the self-purification capacity of the stream. Dyes are usually recalcitrant since they contain azo, nitro or sulfonate groups, and their residues accumulate in the biosphere. The dye effluents have a toxic effect on the germination rates and biomass of several plant species. It will lead to mortality, genotoxicity, mutagenicity and carcinogenicity (https://shodhganga.inflibnet.ac.in/bitstream/10603/28477/12/12_chapter1.pdf). Another major problem is that the coir and textile-manufacturing units consume a considerable amount of water primarily in the dyeing and finishing operations. Many of the coir industries are in the small-scale sector or as cottage industries, which does not have an effluent treatment plant. Thus, the wastewater is directly released to the water bodies near them.

Coagulation and flocculation are important physicochemical operations of wastewater treatment. The most common coagulants are hydrolytic aluminium and iron salts. The main disadvantage of these processes is the formation of large quantities of chemical sludge. Furthermore, aluminium based coagulants also cause an increase of residual aluminium concentration in the purified water. Such residual aluminium is associated with several problems, including reduced disinfection efficiency, loss in hydraulic capacity and potential adverse effects such as Alzheimer's disease. It requires a post-treatment to control corrosion in water distribution networks and thereby increases the cost of the process. In recent years, many researchers have focused on novel flocculants, natural or synthetic organic polymers, such as poly-aluminum chloride (PACl), to replace traditional aluminous coagulants (Zinicovscaia et al., 2016).

Electrochemical methods compete with other physico-chemical technologies to offer solutions to the needs of many industries, such as the purification of different types of wastewater. The principle of the method is the plating-out of metal ions on a cathode surface and their subsequent recovery in the elemental state. The versatility of electrochemical methods (electrocoagulation, electro flotation, electrooxidation, and electro deposition) can be seen in their low environmental impact, easy usage and handling, and lack of harmful or toxic leftovers. Electrocoagulation and electrooxidation are alternatives to classical chemical techniques (Zinicovscaia et al., 2016). Electrocoagulation can reduce the need for chemicals since the electrodes provide the coagulant. The present study focuses on the optimization of the operating parameters for electrocoagulation of dye wastewater. Electrode configuration is also deemed important in the electrocoagulation process and hence an attempt is made to identify the suitable electrode configuration. The application of the developed system on decontamination of coir industry wastewater is also studied.

2 Methodology

Dye wastewater sample of 100 ppm concentration was prepared from 1000 ppm stock solution. The major parameters influencing the electrocoagulation process are flow rate, voltage, electrolyte concentration, pH, and electrode orientation. During the optimization of each parameter, other parameters were kept constant. The flowrate was optimized in the range of 750 mL/h - 1500 mL/h at 250 mL/h increments, keeping the voltage as 8V, NaCl concentration as 1000 mg/L, and electrode orientation as parallel. The voltage was varied from 6V, 8V, 10V and 12V, and optimized keeping the flow rate as 1000 mL/h, NaCl concentration as 1000 mg/L, and electrode orientation as parallel. The electrolyte used was NaCl and its dosage was optimized by varying the concentration from 500 mg/L to 1500 mg/L at 250 mg/L increments, keeping flow rate as 1000 mL/h, the voltage as 8V, and electrode orientation as parallel. The pH dependence of the solution was tested for an initial solution pH of 4,5,6,7, and 8, keeping flow rate as 1000 mL/h, voltage as 8V, NaCl concentration as 1000 mg/L and electrode orientation as parallel. Sodium hydroxide and sulphuric acid were used for pH variation. Different electrode orientations like the series arrangement, inclined arrangement and parallel arrangement were tested, keeping flow rate as 1000 mL/h, the voltage as 8V, and NaCl concentration as 1000 mg/L. Samples were collected from the outlet of the reactor at an interval of 15 minutes and the absorbance value, pH, turbidity and the COD were measured.

2.1 Reactor Design

The electrocoagulation cell consists of a rectangular tank with a floatation tank of total volume 1L and sedimentation tank of 4L as shown in fig.1. Flocculation tank is provided with two iron electrodes of rectangular shape (120mm×70mm×4mm), used as anode and cathode, with immersed electrode surface area of 144cm².

The distance between the two electrodes was kept as 20mm. The electrodes were placed at the middle of the floatation tank. The EC cell was fed continuously with a peristaltic pump. Detention time was varied by adjusting the liquid flow rate between 750 mL/h and 1500 mL/h. The two compartments were connected by a rectangular groove as shown in fig.1. The volume of the second compartment and the position of outlet tube were designed to avoid re-suspension of settled particles. The sludge was essentially recovered by settling.
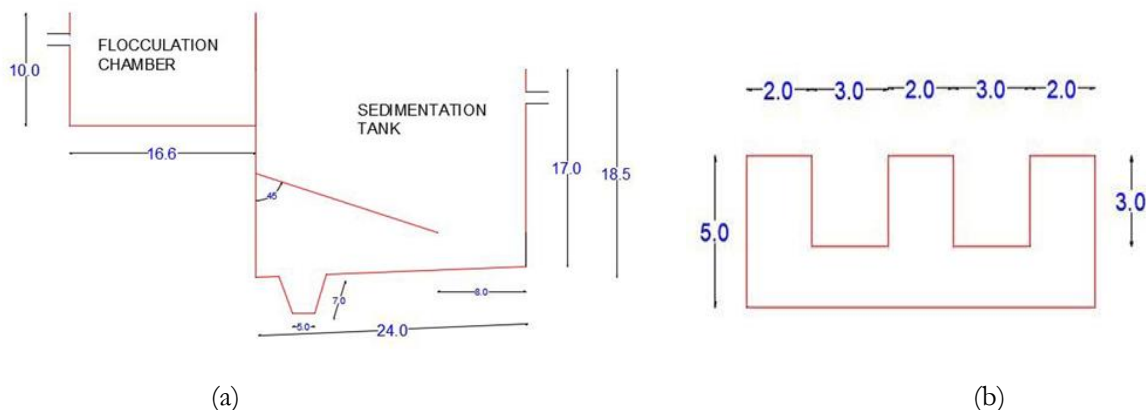

(a)　　　　　　　　　　　　　　　　　　　　　　　　　(b)

Fig.1: Elements of the electrocoagulation reactor (a) Side view of sedimentation tank (b) Cross- sectional view of the weirs (All dimensions are in cm)

3　　Results and Discussions

The influence of operating parameters like the flow rate, voltage, electrolyte concentration, pH and electrode orientation on the electrocoagulation system were studied. The initial COD value of the synthetic dye wastewater was 750 mg/L. and The optimized values of these operating parameters were used to study the treatment of coir industry dye wastewater.

3.1　　Effect of flow rate

To understand the influence of different flow rates, experiments were conducted using iron electrodes by progressively increasing the inlet flow rate Q from 750mL/h 1500 mL/h, at 250 mL/h increments. The colour removal efficiency of the sample for different flow rates is consolidated in Fig. 2a.

It is found that when the flow rate increases, colour removal efficiency decreases for the same current density. In order to get high performance at high flow rate current density needs to be increased. At higher flow rates an insufficient amount of iron hydroxide complexes will be generated. Also, the settling time available for the flocs will decrease. This reduction in flocs will result in reduced colour removal efficiency. The combination of current density and detention time determines the electric charge given in to the system (Emamjomeh et al., 2005).

When the turbidity of the samples at different flow rates was measured, it was found that sample with flow rate 1000mL/h had the minimum value. Initially, there was a decrease in the turbidity of the effluent due to improved efficiency of the treatment at a lower flow rate. The turbidity of the sample at different time interval is given in fig. 2b. But as the flow rate is decreasing, increased detention time will be present in the flocculation chamber. It results in increased floc production. The excess of flocs generated will not contribute much to the colour removal efficiency and will also result in higher turbidity to the effluent. So flow rate 1000mL/h was

selected. At higher flow rate above 1000 mL/hr, there will not be sufficient flocs production and also lesser settling time will be present for them to get settled out. It will result in more turbidity to the effluent.

The chemical oxygen demand (COD) of the sample at different time intervals are as shown in fig. 2c. When flow rate increases COD removal efficiency decreases for the same current density since the quantity of dissolved iron per unit of time and volume is lower.
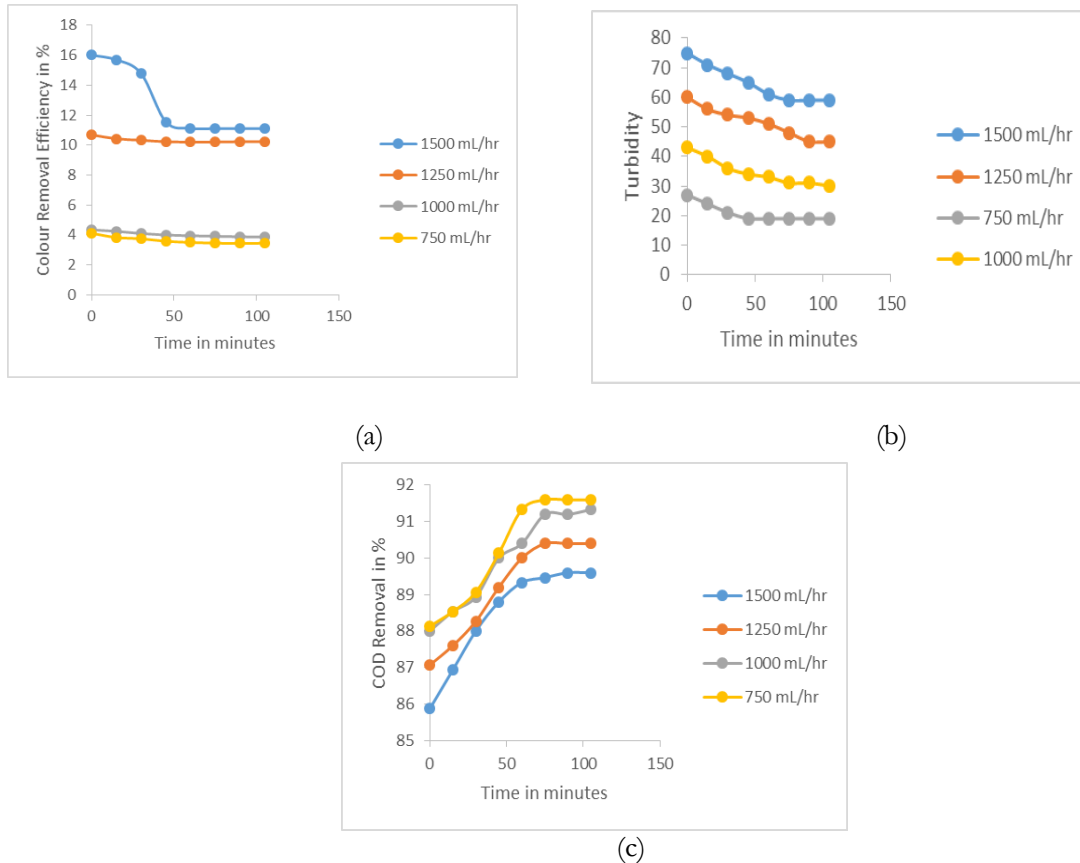

(a)

(b)

(c)

Fig 2: CRE (a), Turbidity (b) and COD (c) of the sample at different time intervals and flowrates (Voltage - 8V, NaCl concentration -1000 mg/L, initial dye concentration – 100 ppm, distance between electrode – 2 cm and electrode orientation - parallel)

3.2   Effect of voltage

Effect of voltage variation was studied in the range 6V to 12 V. The conditions that prevailed during the experiments were flow rate – 1000 mL/h, initial dye concentration – 100ppm, inter-electrode distance – 2cm, electrolyte concentration – 1000 mg/L, electrode orientation- parallel (Fig. 3a). With an increase in voltage, the current density increases which leads to anode dissolution i.e., leaching of electrodes. At high voltage more coagulant is available per unit time which is unnecessary and unsafe for drinking and uneconomic in terms of energy consumption. 80% of operating cost is of electrode consumption so that needs to be kept in check. It is found that for high current densities abatement of the various pollution variables occurs in two phases. The first phase of decreasing pollution features, or the 'reactive stage' during which the COD and the turbidity removal yields increase with the current density. This can be explained by the fact that iron ions production resulting from anode dissolution increases with current density. In the second period, a further increase in iron

concentration has no further effect on the treatment. Indeed, the suspended and dissolved organic matters were no longer limited despite the higher iron concentrations allowed by longer periods of Fe anode dissolution (M. Bayramoglu et al., 2004).

It was observed that sample at voltage 8V had the minimum turbidity value (figure not attached). At a lower voltage, an insignificant number of flocs will be generated due to low current density. Thus, the treatment efficiency will be lowest and results in the turbidity to the sample. At higher voltages, higher current density causes more floc generation. But the generation of iron hydroxides in excess will not contribute much to the colour removal efficiency and will results in turbidity to the sample (Chen et al., 2000). Voltage 8V was selected for further investigations.

The chemical oxygen demand of the sample at different time intervals for different voltages are fig. 3b. It was found that when the voltage increases COD removal efficiency increases. Colloidal particles have surface negative charges. In electrocoagulation colloidal particles are destabilized by giving positive charges and thus the formation of flocs occurred. As the voltage increases anode dissolution is more. If an additional electrical charge is supplied to the charged particles via electrocoagulation reactor's electrodes the surface charge of colloidal particles is neutralized and several molecules combine into larger and separable agglomerates.
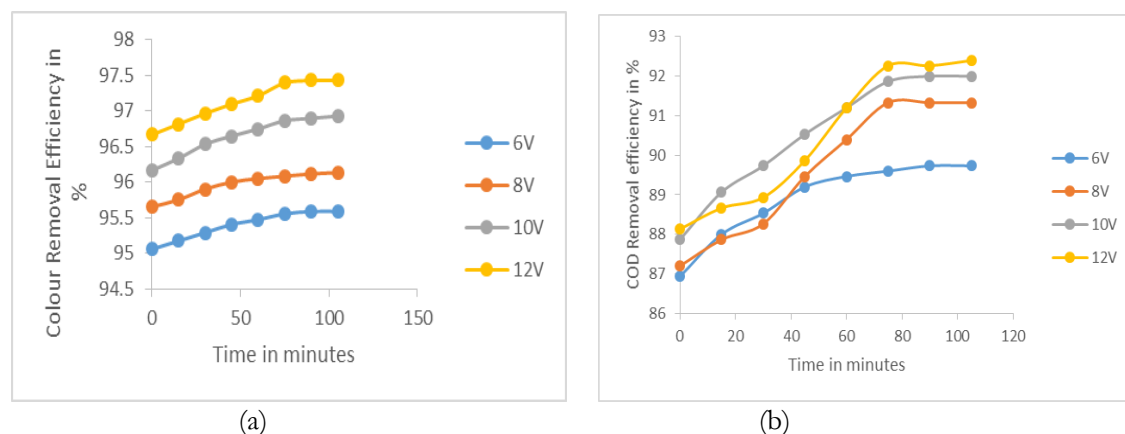

| (a) | (b) |

Fig. 3: The CRE (a) and COD (b) of the sample at different time intervals and voltage (flow rate – 1000 mL/h, initial dye concentration – 100ppm, inter-electrode distance – 2cm, electrolyte concentration – 1000 mg/L, electrode orientation- parallel)

3.3 Effect of electrolyte concentration

Electrolyte concentration was varied in the range of 500 mg/L to 1500 mg/L and tested. The conditions that prevailed during the experiments were: flow rate – 1000 mL/hr, initial dye concentration – 100 ppm, inter-electrode distance – 2cm, Voltage – 8V, electrode orientation- parallel. The colour removal efficiency at different time intervals is given in fig.4a. Sodium chloride (NaCl) is usually employed to increase the conductivity of the water or wastewater to be treated. Wastewater conductivity affects faradic yield, cell voltage and therefore energy consumption in EC cells. Besides, increasing water conductivity using NaCl has other advantages e.g. chloride anions could significantly reduce the adverse effects of other anions, such as $(HCO_3)^-$ ions.
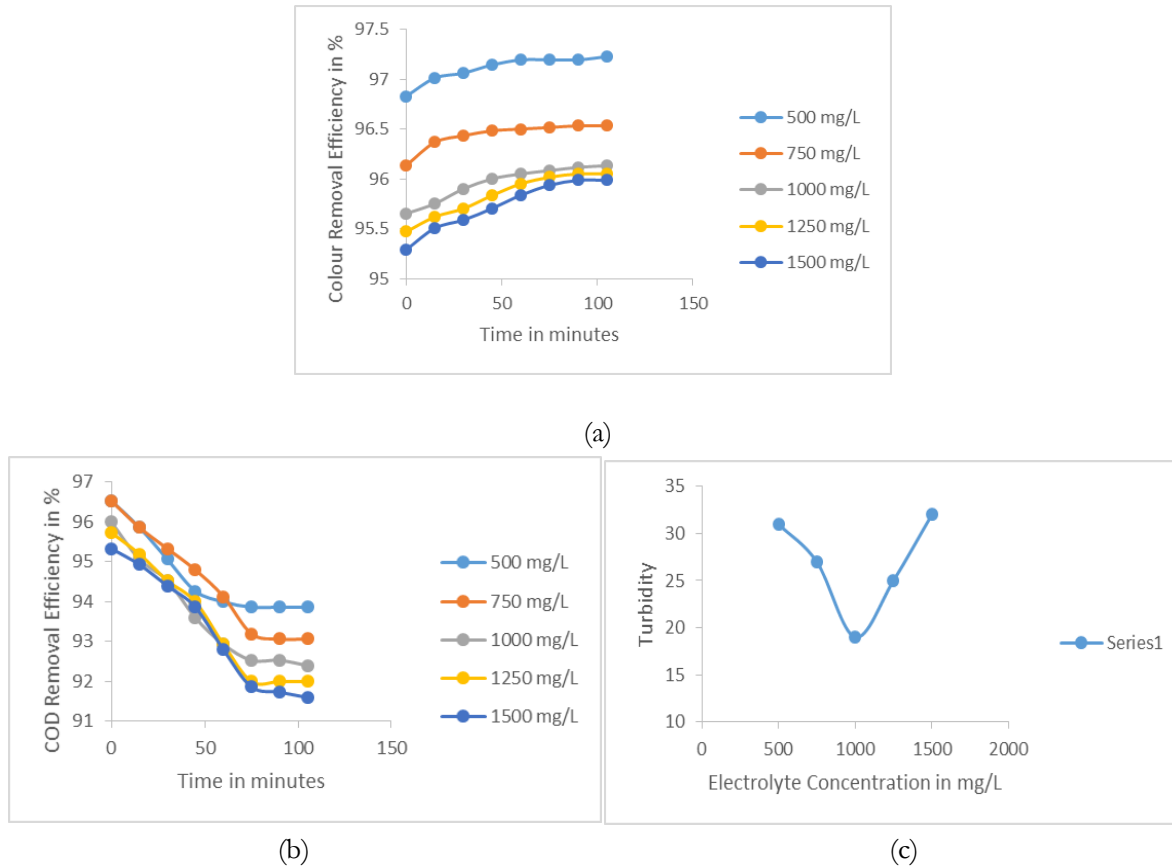
Fig. 4: CRE (a) and COD (b) of the sample at varying electrolyte concentration at different time intervals and turbidity (c) at varying electrolyte concentration (flow rate – 1000 mL/hr, initial dye concentration – 100 ppm, inter-electrode distance – 2cm, Voltage – 8V, electrode orientation- parallel.)

An excessive amount of NaCl induces overconsumption of the iron electrodes due to "corrosion pitting". As the NaCl concentration increases colour removal efficiency decreases. Working without NaCl could be the best solution to maximize dye removal and a good way of minimizing operating cost. The COD removal efficiencies of the sample at different time intervals for different electrolyte concentration as shown in fig. 4b. It was found that when electrolyte concentration increases COD removal efficiency decreases. But increasing electrolyte concentration reduces the current consumption. Thus, operating cost can be controlled.

When the turbidity of the samples at different electrolyte concentration was measured it was found that sample with electrolyte concentration 1000 mg/L had the minimum value (Fig. 4c). It is because, at higher electrolyte concentration, more iron hydroxides will generate due to higher current flow and results in increased turbidity. At lower concentration, there will not be sufficient current density and floc generation. So the treatment efficiency will be lowest. So electrolyte concentration of 1000 mg/L was selected for further studies.

3.4 Effect of initial pH

The influence of initial pH was studied in the pH range 4 - 8. The colour removal efficiency at different time intervals are given in fig. 5a. The electrocoagulation process is highly dependent on the pH of the water or wastewater to be treated. The initial pH is one of the important solution chemistry factors in terms of raw water

but also as a potential operational variable. pH will affect the speciation of Fe. Iron hydroxide is formed by hydrolysis and its solubility is dependent on pH and ionic strength. The form insoluble flocs in a pH range between 6 and 7. (Emamjomeh et al., 2005). Therefore the colour removal efficiency is maximum in this range. The turbidity at different time intervals is shown in fig. 5b. When the turbidity of the samples at different pH were measured, it is found that sample with pH 7 had the minimum value. So, pH 7 was selected as the optimum initial pH. The COD removal efficiency of the sample at different time intervals for different initial pH are shown in fig.5c. To investigate the effect of the pH on the COD removal efficiency, the initial pH of the sample was progressively increased from 4 to 8. Removal efficiency is maximum in the initial pH range of 5 and 7 since insoluble flocs are formed in this region.
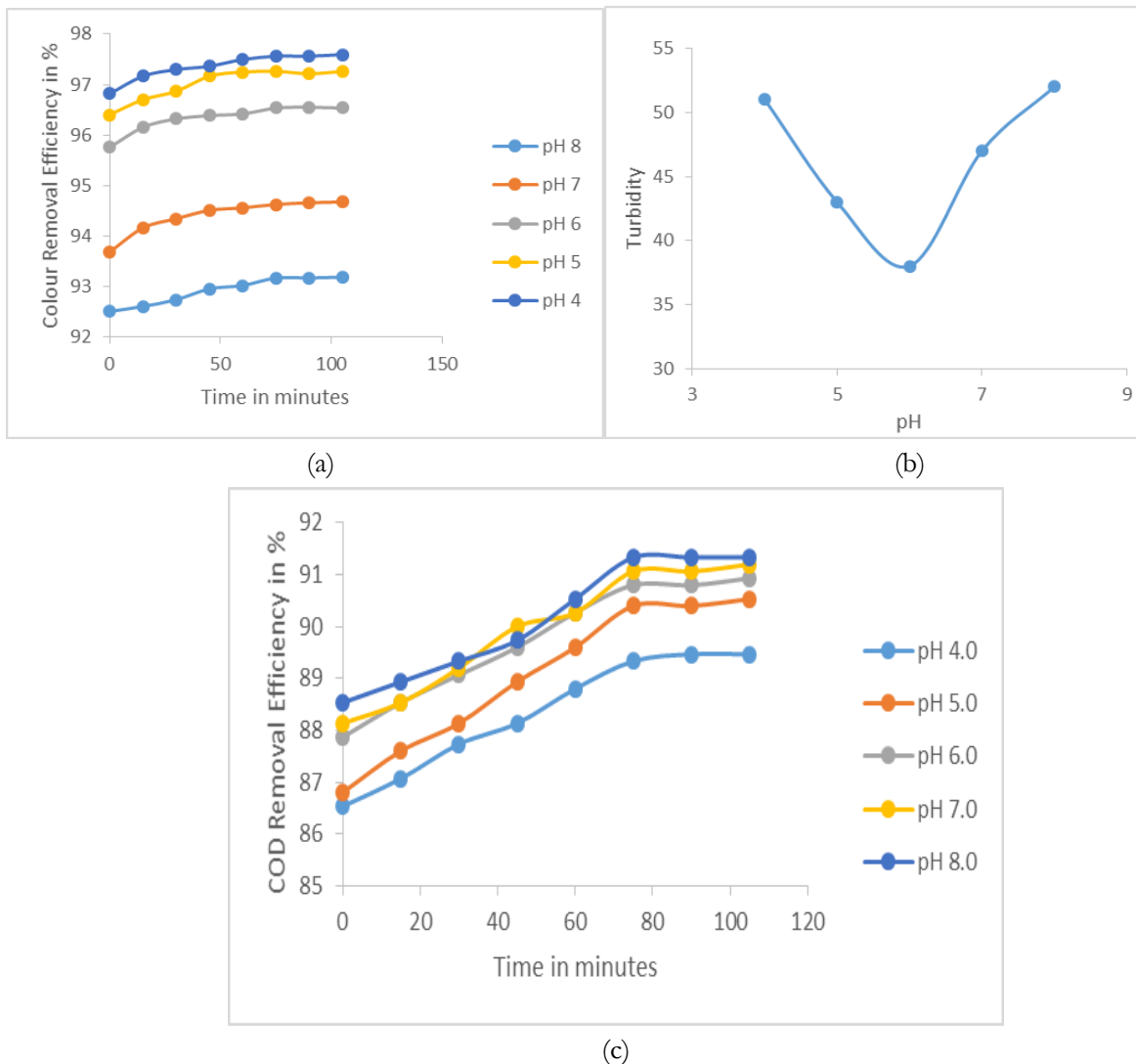

(a)

(b)

(c)

Fig. 5: (a) The CRE of the sample at different time intervals (b) Turbidity at different pH (c) The COD of the sample at different time intervals (flow rate – 1000 mL/h, initial dye concentration – 100ppm, electrolyte concentration – 1000 mg/L, inter-electrode distance – 2cm, Voltage – 8V, electrode orientation- parallel.)

3.5   Effect of electrode configuration

In order to understand the effect of electrode orientation on efficiency electrodes were kept in parallel, inclined and series. The conditions that prevailed during the experiments were. The colour removal efficiency and COD removal at different electrode orientation are depicted in fig.6.

Parallel electrode configuration was found to have the best colour removal capability. In the case of inclined and series there is high turbulence and a chance of short circuiting and formation of dead zones. Due to dead zones effective volume of flocculation chamber decreases (Emamjomeh et al., 2005). Hence, the parallel configuration was selected. The COD removal efficiencies of the sample at different time intervals for different electrode orientation are shown in fig.8b.

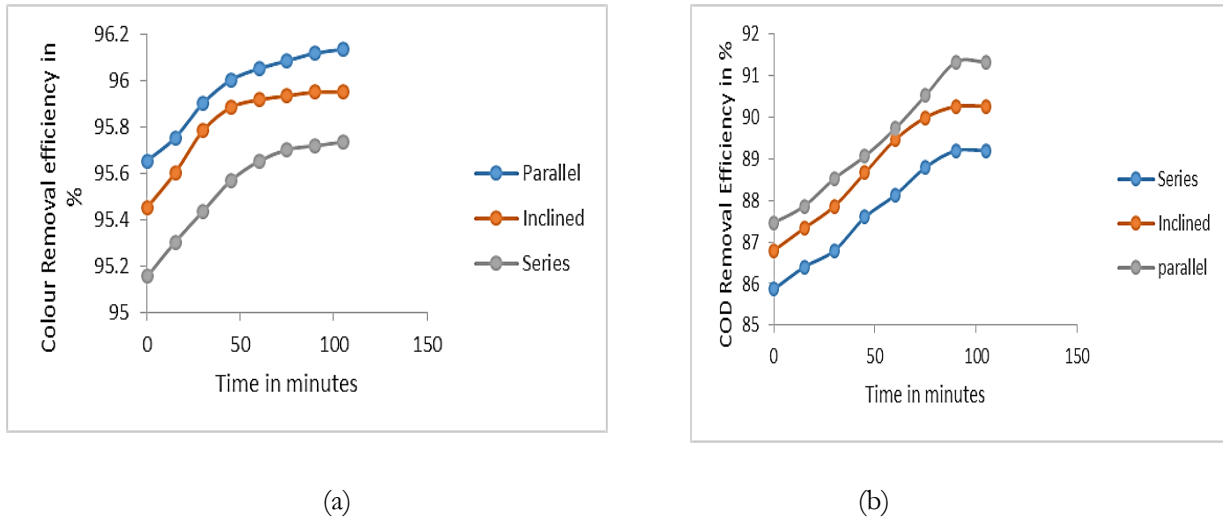(a)   (b)

Fig. 6: The CRE (a) and COD (b) of the sample at different time intervals and electrode configuration (flow rate – 1000 mL/h, initial dye concentration – 100 ppm, Electrolyte concentration – 1000 mg/L, Voltage – 8V, inter-electrode distance – 2cm)

3.6   Performance evaluation of electrocoagulation in the removal of industrial dye

Coir industry dye wastewater was collected from the Coir Research Institute, Alappuzha. There was no need for adding electrolyte as the real wastewater collected had sufficient conductivity. To investigate the performance of continuous flow electro-coagulation for the degradation of industrial dye, optimized values of the parameters for methyl orange (i.e. Flow rate - 1000 mL/h, Voltage - 8V, Electrolyte concentration – 1000 mg/L, pH - 6.0, Electrode Orientation – Parallel) were used and a colour removal efficiency of 91.63 % was obtained. The characteristics of the raw and treated wastewater are shown in Table 1. The pH of the treated sample exceeds discharge standards and appropriate pH correction is needed before final disposal.

Table 1: Characteristics of raw and treated wastewater

Parameter	Raw wastewater	Treated wastewater
pH	6.8	8.7
BOD	1488 mg/L	116 mg/L
COD	3261 mg/L	147 mg/L
Turbidity	96 NTU	25 NTU

The initial BOD of the dye wastewater was 1488 mg/L. By the continuous flow electrocoagulation treatment, it was reduced to 116 mg/L. That is 92.20% removal efficiency was obtained. The pH of the water was raised from 6.80 to 8.7 during the treatment process.

4   Conclusion

Continuous flow experiments were designed to investigate the effects of the different parameters including flow rate, voltage, pH, electrolyte concentration, electrode configuration on the dye wastewater treatment by electrocoagulation process. The removal efficiency was found to be dependent on the above parameters. It was found that when flow rate increases, the removal efficiency decreases, for the same current density. So inorder to get high performance at high flow rate, current density needs to be increased. The highest treatment efficiency was obtained for the largest voltage as leaching of electrodes were more. However, it is advisable to limit the voltage to avoid excessive energy consumption and turbidity. As the NaCl concentration increases colour removal efficiency decreases. Working without NaCl could be the best solution to maximize dye removal. The colour removal efficiency is maximum in between initial pH 6 and 7 as insoluble stable flocs are formed in this region. . It was found electrode configuration which was kept in parallel was found to be had the best treatment efficiency. For electrocoagulation of coir industry wastewater in a continuous flow cell with iron electrodes the optimum flow, voltage, pH, electrolyte concentration and electrode orientation adopted were 1000 mL/h, 8 V, 7, 1000 mg/L and parallel configuration respectively. After reaching a steady state in the continuous flow reactor the values of colour removal efficiency, turbidity, COD, BOD obtained were 92.17%, 25 NTU, 147mg/L and 116 mg/L respectively.

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