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Optimization of Operational Parameters for Treatment of Domestic Wastewater Using Electro-Coagulation

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ABSTRACT

The present study was conducted to investigate the optimal parameters for electro-coagulation treatment of domestic wastewater. The laboratory scale experiments were carried out in batch mode using iron (Fe) electrodes and direct current at ambient conditions. The different factors were considered to assess the removal efficiency of COD, TSS and turbidity like, pH (5-9), treatment time (15-60 min), current density (0.2-0.8 mA/cm^2) and NaCl dose (0.71-2.86 g/l). The optimal values of the influencing factors were obtained at a pH of 8, current density of 0.6 mA/cm^2 (14 V), treatment time of 45 min and NaCl dose of 2.86 g/l. There was a positive relation between COD, TSS and turbidity removal efficiency from the wastewater and the pH in the range of 5-8. The removal efficiency of 85.7% COD, 90.8% of TSS and 96.6% of turbidity showed potential usefulness of the electro-coagulation process for remediation of pollutants from the domestic wastewater. The high efficacy of pollutants removal makes electro-coagulation process a suitable option for the domestic wastewater remediation.

Key words: Electro-coagulation, optimization studies, wastewater treatment, chemical oxygen demand, iron electrodes

INTRODUCTION

Water is a vital resource for socio-economic well-being and sustaining biodiversity. India stands at 120th position among 122 countries in terms of the water quality index (Ministry of Jal Shakti, 2019). The population explosion and industrialization are primary causes of wastewater generation. The wastewater generation is projected to increase to 574 billion m^3/ year by 2050 globally (Qadir *et al.*, 2020). Nearly 62.5% of the wastewater is untreated or partially treated in urban India owing to inadequate infrastructure (Nath and Parmar, 2022). The domestic wastewater is characterized with a diverse range of organic and inorganic contaminants, nutrients, bacteria, protozoa and viruses which produce deleterious impacts in the aquatic ecosystems (Al-Mawla *et al.*, 2023). Water pollution is reported to induce behavioural and physiological changes in the exposed species, eutrophication and alteration of community structure (Bhat and Qayoom, 2021).

Various physico-chemical and biochemical technologies have been utilized for remediation of pollutants from the wastewater (Moussa *et al.*, 2017). They come with some comparative drawbacks which limit their large scale application. Electro-coagulation (EC) is reported to be an efficient and advantageous technique over the conventional wastewater treatment methods. EC is an electrochemical process which involves destabilization of the dissolved, suspended, or emulsified pollutants in the wastewater with the help of electricity. The destabilized pollutants are subsequently removed by coagulation, flocculation and sedimentation (Tegladza *et al.*, 2021). The coagulant is generated *in-situ* by dissolution of metal (M^{n+}) from the anode with simultaneous production of hydrogen (H_2) gas and hydroxyl ions (OH^-) at the cathode. The cation (M^{n+}) and OH^- ions interaction eventually generates metal hydroxides which have high absorption affinity for the pollutants. The metal hydroxides and pollutants reaction produces a neutralized matter which aggregates followed by sweep coagulation. H_2 gas helps to float the flocculated particles at the surface of water (Fig. 1).

EC has been effectively combined with processes like microwave, ozonation,

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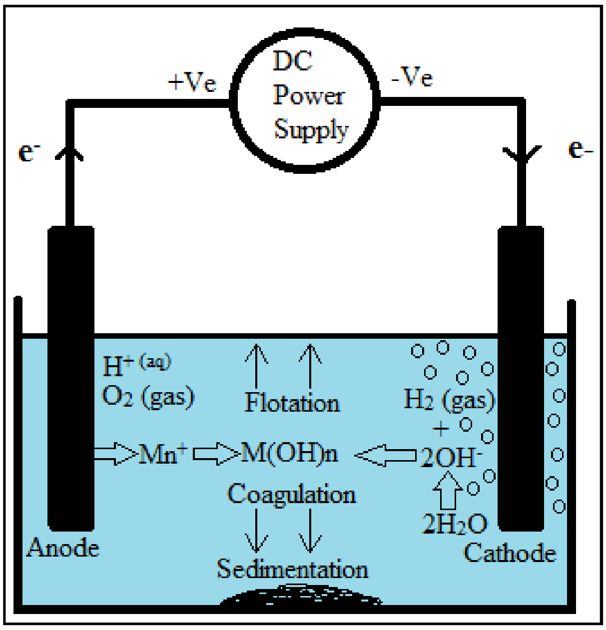

Fig. 1. The mechanism of EC treatment of wastewater.

microfiltration and ultrasonic for efficient degradation of pollutants from the wastewater (Abdulhadi *et al.*, 2021; Elhadeuf *et al.*, 2023). This paper investigated the optimal parameters for the EC treatment of domestic wastewater using Fe-Fe electrodes and DC as source of energy. The pollutants removal efficiency was evaluated in terms of the percentage removal of chemical oxygen demand (COD), total suspended solids (TSS) and turbidity from the wastewater.

MATERIALS AND METHODS

The domestic wastewater samples utilized in the present study were collected from the outlet of primary clarifier of a nearby sewage treatment plant. The wastewater samples were stored at 4°C in refrigerator before use in the EC studies. The iron electrodes were purchased from a workshop. The wastewater pH was adjusted to the desired value using 1 molar solution of H_2SO_4 and NaOH. The NaCl was obtained from Fisher Scientific (SQ grade) and was used as electrolyte. Rest of the chemicals and reagents utilized were of analytical grade. The current and voltage values of the circuit were read using a digital multi-meter.

Electro-coagulation system comprised a 1000 ml glass beaker fitted with 2 iron electrodes of dimension 12 cm × 6 cm × 1.5 mm (length, width and thickness) which acted as both cathode and anode. The electrodes were hanged vertically in the beaker using a wooden support and parallel to each other with mono-polar configuration. The parallel arrangement minimized energy consumption by lowering the potential difference between the electrodes (Brahmi *et al.*, 2019). The electrodes were kept 1 cm apart from each other for proper electrolyte movement and efficient pollutants removal (Mousazadeh *et al.*, 2021). The electrodes were connected with a direct current (DC) power supply and kept completely submerged within wastewater throughout the experiments. EC studies were carried out with 700 ml aliquot of primary clarified domestic wastewater. The wastewater was adjusted to the desired pH and an appropriate amount of NaCl was added before experiments. The reaction mixture was agitated (100 rpm) using a magnetic stirrer during EC experiments.

The effect of various reaction parameters i.e. pH (5-9), treatment time (15-60 min), current density (CD) (0.2-0.8 mA/cm^2) and NaCl concentration (0.71-2.86 g/l) on the rate of EC was examined. The pollutants degradation rate was evaluated in terms of the percentage removal of COD, TSS and turbidity from the wastewater (Eq. 1).

$$\text{Degradation (\%)} = \left[\frac{I_0 - F}{I_0}\right] \times 100 \quad \text{...(Eq. 1)}$$

Where,

I_0=Initial concentration of pollutant

F=Final concentration of pollutant after treatment.

All the experiments were carried out in triplicate at ambient conditions and average values were reported.

The wastewater samples were analyzed before and after EC treatment following the standard methods. COD was estimated by closed reflux titrimetric method. Turbidity was determined using laboratory scale digital turbidity meter. The wastewater pH measurements were carried out using a bench scale pH meter (TOSHNIWAL). The total suspended solids (TSS) were measured following gravimetric method. All the analyses were performed in triplicate and average values were reported.

The statistical analysis of data was done using SPSS software (version 23). Analysis of variance (one way ANOVA) was performed followed by post hoc Tukey's all pair wise multiple comparison test ($P < 0.05$) to compare the means of different parameters.

RESULTS AND DISCUSSION

The domestic wastewater was characterized in terms of the various physico-chemical parameters i.e. pH, turbidity, TSS, total dissolved solids (TDS), COD and biochemical oxygen demand (BOD) (Table 1). The wastewater had a low TDS content (697 mg/l) which resulted in low electrical conductivity. Therefore, NaCl was added during EC experiments as a supporting electrolyte to ensure proper electrical conductivity in the wastewater. The wastewater showed a moderate organic load with a 90 and 336 mg/l of BOD and COD. The wastewater presented low biodegradability with a BOD/COD ratio of 0.27. Hence, EC as an advanced wastewater treatment was needed to degrade refractory organics from the wastewater.

Table 1. Physico-chemical characteristics of the primary clarified domestic wastewater

Parameter	Value
BOD (mg/l)	90±4.7
COD (mg/l)	336±3.2
pH	7.29±0.1
Turbidity (NTU)	112±5.6
TDS (mg/l)	697±8.8
TSS (mg/l)	110+4.1

The EC process was optimized by varying various reaction parameters i.e. pH (5 - 9), CD (0.2-0.8 mA/cm^2), treatment time (15-60 min), and NaCl dose (0.71-2.86 g/l). The pollutants removal efficiency was evaluated in terms of the percentage removal of COD, turbidity and TSS from the wastewater before and after the EC treatment.

The pH was an important reaction parameter to influence the efficiency of the EC process (Kumar *et al.*, 2018). The wastewater samples were adjusted to the desired pH (5-9) and subjected to the EC treatment for 30 min at constant CD (0.2 mA/cm^2) and NaCl dose (1.4 g/l). There was observed a positive relation between COD, TSS and turbidity removal efficiency from the wastewater and the pH in the range of 5-8. This was due to the H_2 gas evolution at the cathode and increased hydroxyl ion (OH^-) generation in the solution which ultimately enhanced pollutants removal efficiency (Asaithambi, 2016). The maximum

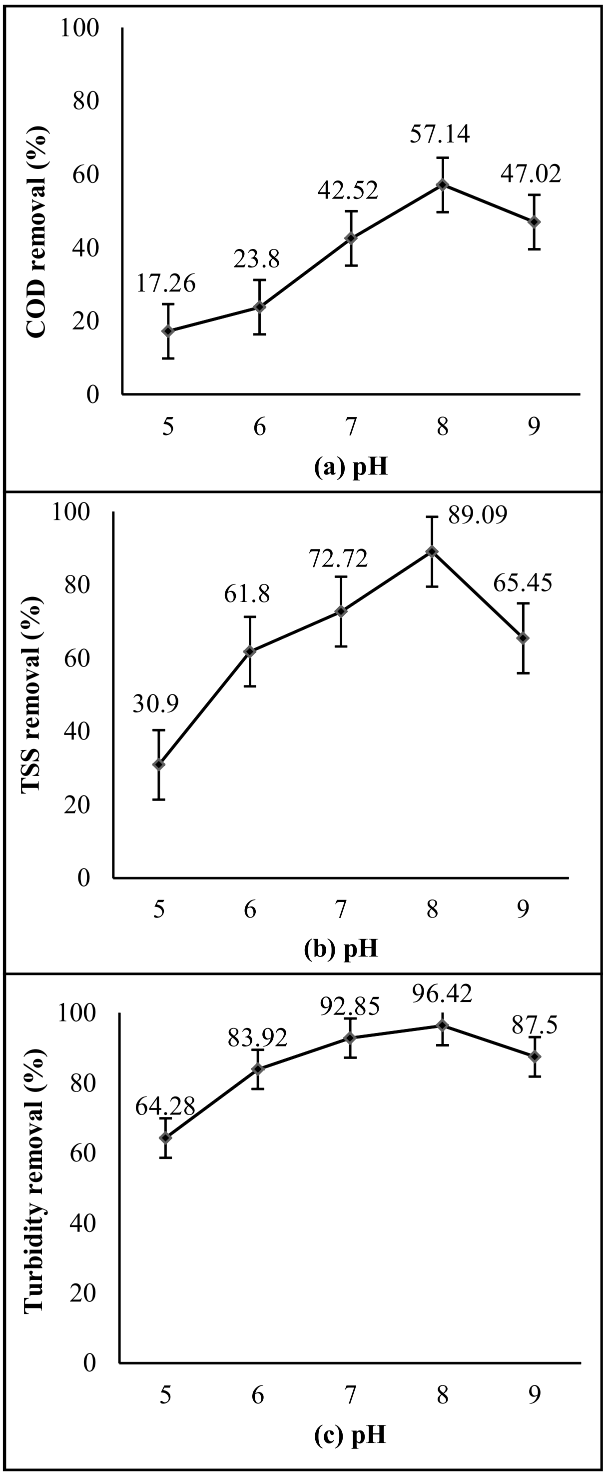

Fig. 2. Percent (a) COD, (b) TSS and (c) turbidity removal by EC treatment as a function of initial wastewater pH (Treatment time 30 min, CD 0.2 mA/cm^2 and NaCl 1.4 g/l).

COD (57.14%), TSS (89.09%) and turbidity (96.42%) removal was achieved at a pH of 8.0 (Fig. 2a, b and c). The COD, TSS and turbidity removal efficiency declined above pH 8.0. Azzouzi *et al.* (2019) also reported minimal pollutants removal efficiency at a high pH of the wastewater. The pH governs the existence of different ions and hydroxide complexes as active coagulant species in the solution. There was higher efficacy of EC process in a pH range of 5.5-8.5 because of poor solubility of the metal hydroxides (Treviño-Reséndez *et al.*, 2023). There was more COD, TSS and turbidity removal at a pH of 8. The natural pH of the primary clarified domestic wastewater varied from 7.2-8. Hence, pH 8 was selected as optimum for the further studies.

The treatment time for electrolysis is an important parameter to influence pollutants removal efficiency and cost of the treatment. The wastewater was treated by varying treatment time (15, 30, 45 and 60 min) at constant pH (8), CD (0.2 mA/cm^2) and NaCl dose (1.4 g/l). A sharp increase was observed in the pollutants removal efficiency during first 30 min of the treatment. The maximum pollutants removal efficiency was achieved at 45 min i.e. 80.95, 72.72 and 85.71% removal of COD, TSS and turbidity, respectively (Fig. 3a, b and c). It is due to the generation of more hydroxyl radicals (OH^-) and metal polymeric species (Asaithambi *et al.*, 2016) in the solution which enhanced pollutants removal efficiency.

The pollutants removal efficiency declined afterwards with further increase in the treatment time. Rumky *et al.* (2020) also reported slight reduction in the pollutants removal efficiency of the EC process at the higher treatment time (30-80 min). Can-Güven (2021) reported no significant improvement in the COD removal efficiency from the produced water beyond 30 min of EC treatment. The pollutants removal efficiency decreased slightly when treatment time increased further from 40 to 50 min owing to the high electrode and energy consumption. Hence, 45 min were selected as optimum treatment time for the EC treatment of the wastewater.

Current density (CD) is defined as ratio between the current and surface area of the electrode which governs generation of coagulant dose and H_2 gas at the anode and cathode, respectively (Priya *et al.*, 2020). EC treatment of the domestic wastewater was carried out by using DC current supply. The wastewater was subjected to EC treatment by

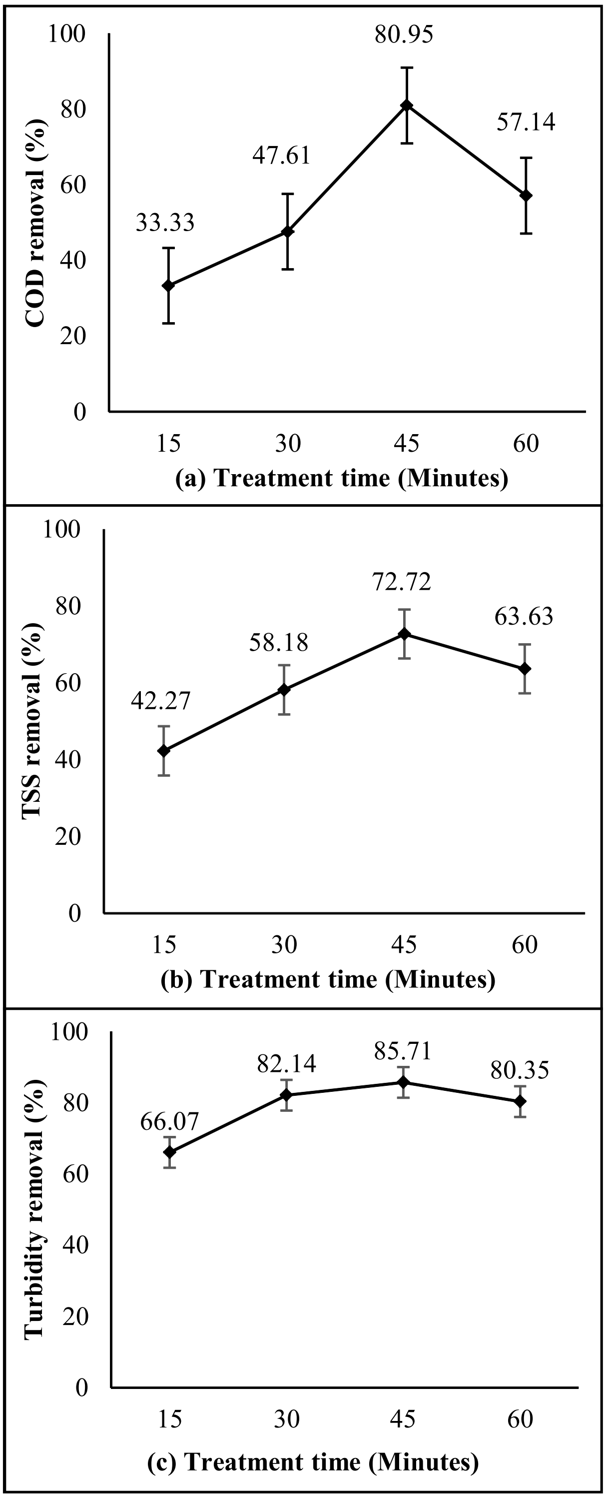

Fig. 3. Percent (a) COD, (b) TSS and (c) turbidity removal by EC treatment as a function of treatment time (pH 8, CD 0.2 mA/cm^2 and NaCl 1.4 g/l).

varying CD (0.2, 0.4, 0.6 and 0.8 mA/cm^3) at a constant pH (8), NaCl dose (1.4 g/l), and treatment time (45 min). There was observed increased removal of COD, TSS and turbidity from the wastewater as the CD increased from 0.2 – 0.6 mA/cm^2. There was direct relationship between the CD and the rates of coagulant and bubble formation which in turn increased the pollutants removal efficiency from the wastewater. The size of the gas bubbles reduced at high density which led to enhanced removal of pollutants through flotation and sludge settling (Sharma and Verma, 2017). There was maximum removal of COD (85.71%), TSS (83.63%) and turbidity (91.07%) from the wastewater at a CD of 0.6 mA/cm^2 (Fig. 4a, b and c). COD, TSS and turbidity removal efficiency declined with further increase in the CD. The high CD may decline the performance of the EC process owing to the secondary reactions, promotion of ohmic and voltage drop between cathode and anode, and particle re-stabilization (Priya *et al.*, 2020). Hence, CD 0.6 mA/cm^2 was found to be optimum for the EC treatment of wastewater. The electrolyte concentration is an important parameter to influence the pollutants removal efficiency during EC process. There was NaCl as a supporting electrolyte during EC treatment of the domestic wastewater. The wastewater was electro-coagulated using 0.71, 1.43, 2.14 and 2.86 g/l of NaCl dose at a pH of 8, CD of 0.6 mA/cm^2 and treatment time of 45 min. There was increased removal of COD, TSS and turbidity from the wastewater with increase of NaCl dose.

NaCl addition enhances conductivity of the wastewater which in turn increases the production of oxidizing species to ultimately enhance pollutants removal efficiency (Bote *et al.*, 2021). The maximum removal of COD (83.92%), TSS (90.9%) and turbidity (96.6%) was achieved at a NaCl dose of 2.86 g/l which was significantly higher as compared to the results obtained at lower doses of NaCl (Fig. 5a, b and c). Hence, NaCl dose of 2.86 g/l was found optimal for EC treatment of wastewater. The above findings are in good agreement with those of Sharma and Verma (2017).

CONCLUSION

The electro-coagulation efficiently degraded organics from the domestic wastewater. The

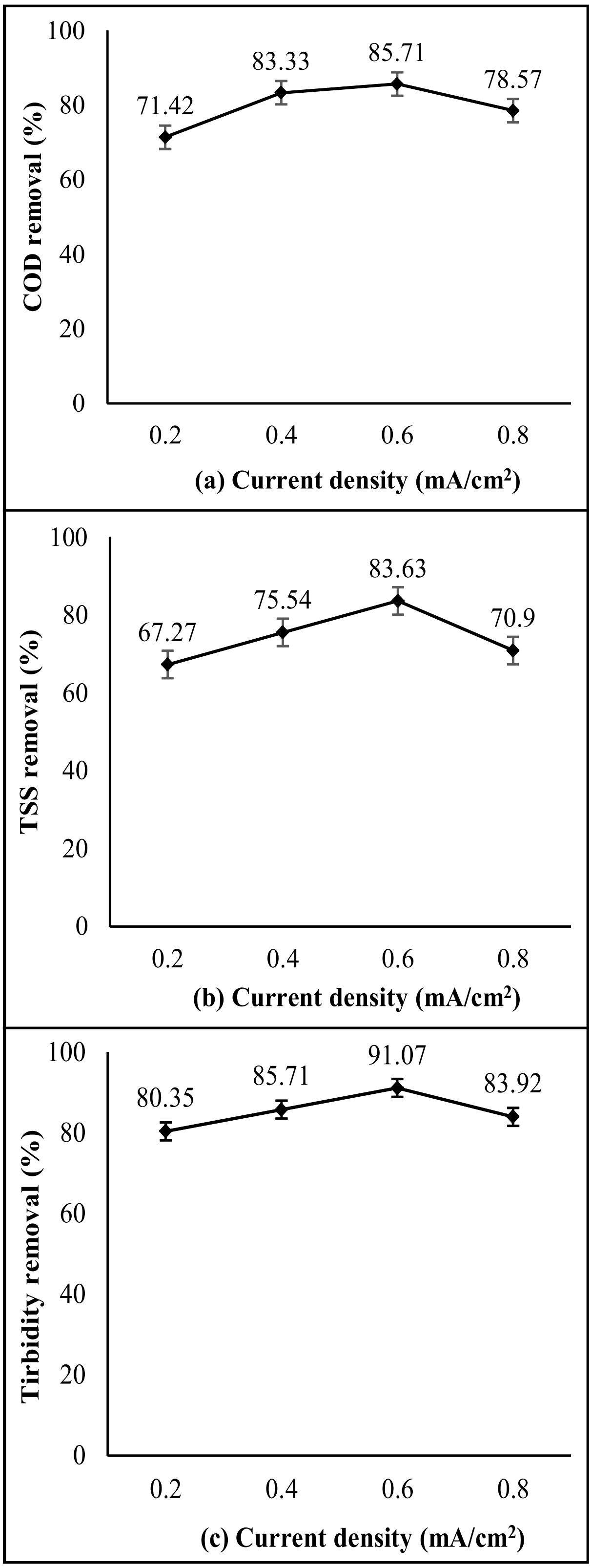

Fig. 4. Percent (a) COD, (b) TSS and (c) turbidity removal by EC treatment as a function of CD (Treatment 45 min, pH 8 and NaCl 1.4 g/l).

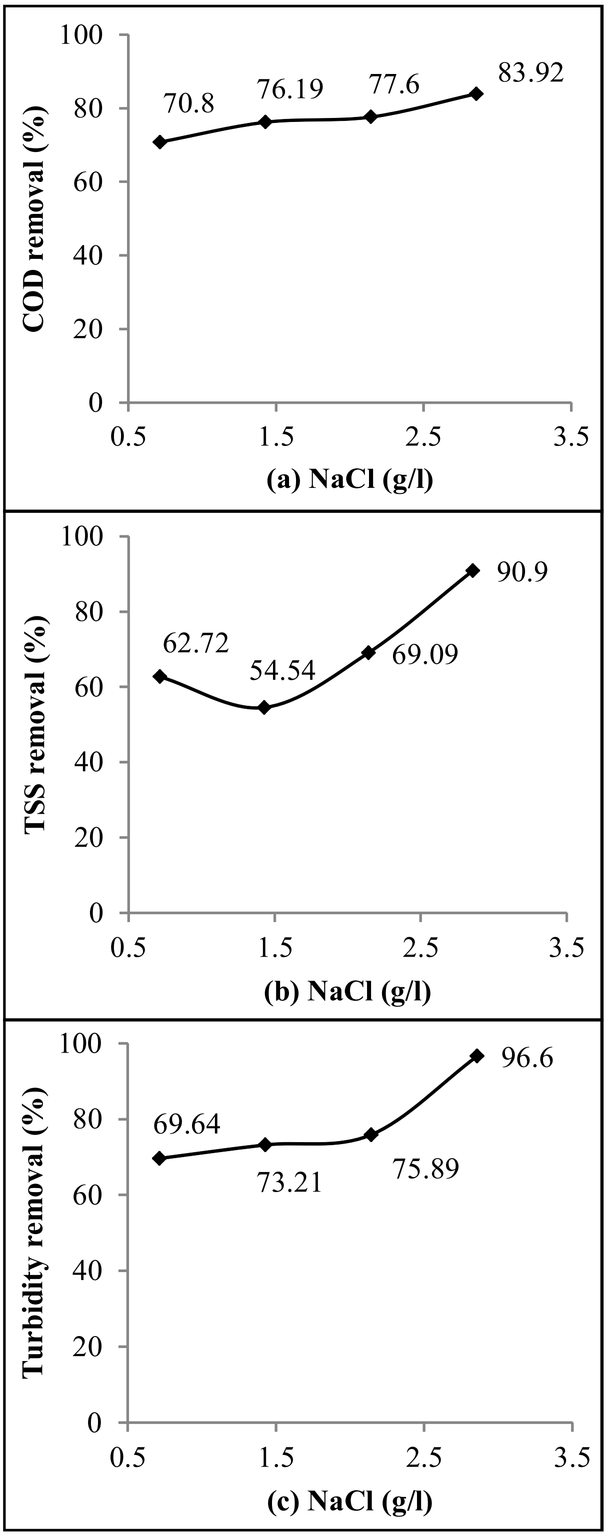

Fig. 5. Percent (a) COD, (b) TSS and (c) turbidity removal by EC treatment as a function of NaCl dose (Treatment time 45 min, pH 8 and CD 0.6 mA/cm^2).

wastewater pH, treatment time, applied CD and electrolyte dose were the significant operational parameters which strongly influenced the COD, TSS and turbidity removal efficiencies. The COD, TSS and turbidity removal efficiency increased with increasing value of treatment time (15-60 min), wastewater pH (5 - 9), CD (0.2 - 0.8 mA/cm^2) and NaCl dose (0.71-2.86 g/l). The best operational conditions obtained were: treatment time of 45 min, wastewater pH of 8, CD of 0.6 mA/cm^2 and NaCl dose of 2.86 g/l. The electro-coagulation was found to be a potential method for remediation of pollution load from the domestic wastewater.

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