ATIPC – 2020 Special Issue

J. Indian Chem. Soc.,
Vol. 97, No. 12b, December 2020, pp. 2713-2719

The effect of current density and charge loading for total organic carbon (TOC) removal by electrocoagulation

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Manuscript received online 04 December 2020, accepted 24 December 2020

In this research the effect of current density and charge loading was investigated on the removal of total organic carbon (TOC) from a synthetic water sample. It was noted that during Electrocoagulation (EC) at a constant current density, TOC removal was increased when charge loading was increased. However, for a constant charge loading, the TOC removal was decreased when the current density was increased. Therefore, the investigation pointed out anomalously, that the indiscriminate growth of current density does not only decrease the TOC removal but also cause economic loss.

Keywords: Total organic carbon (TOC), electrocoagulation (EC), current density, charge loading.

Introduction

The extent and unprejudiced of water treatment are to remove objectionable constituents from water to make it potable. The conventional water treatment process uses alum coagulation, especially for the separation of suspended solids. In subsequent operations like filtration and disinfection water is make pathogen free. However, the trace amounts of dissolved organic substances which interfere with the disinfection process and produces carcinogenic disinfection byproducts (DBPs) are the major concern which remain unattended during treatment. Though electrocoagulation is widely used for wastewater treatment, the systematic study on different EC process variables is still not rigorously studied for potable water. Natural waters are drawn from different surface water sources contain a wide variety of water quality parameters among those suspended and colloidal particles are the commonest which is responsible for turbidity in surface water. These contaminants may be generated from organic and inorganic sources. The negatively charge of colloids on the surface exhibited repulsion forces and the aggregation between the colloids get hampered[1,2]. The process of EC is easily operated by simple equipment for the dosing of coagulant in experiment and the sludge generation is quite less than another conventional counterpart[3]. The associated anions are not produced in EC like chemical coagulation and easy to maintain the environmentally friendly compatibility[4,5]. The electrocoagulation process exhibits lower operational costs for low and intermediary doses of coagulant compared with conventional coagulation with aluminum polychloride (PACl)[6]. Thus, the cost of the electrocoagulation process relates favorably with that of conventional coagulation for less coagulant demands[7] and the effective workability may partially replacement of the chemical coagulation[8].

TOC impart unfavorable taste and visual effect in water samples. This organic compound coordinates with different metallic ligand and transmit metal complexes to the natural water sources[9,10]. During the disinfection procedure this compound mixed with disinfectant in water and produce disinfection by-products (DBPs). Human population faced carcinogenic, mutagenic toxic effects due to different DBP's like, trihalomethanes, halo acetic acids etc. Due to the health consideration this fulvic acid compound must be removed from the water for drinking water treatment process[11].

The removal of TOC from the contaminated water has been described in the literature with the additional arrangement of traditional water treatment method such as coagulation/flocculation, ion-exchange, membrane filtration, adsorption adopted etc.[12]. But, conventional adsorption methods by using activated carbon and polymers are not effective due to very wide size range of dissolved natural organic acids from the water sample[13]. In the last few decades nanotechnology was rapidly adopted in water treatment process[14–16]. The pretreatment by coagulation and flocculation followed by sedimentation/flotation and filtration are commonly practiced for the separation of natural organic matter (NOM) economically. The hydrophobic or high molecular weight (HMW) fractions of NOM are effectively removed by the pretreatment of coagulation-flocculation. But the hydrophilic or low molecular weight (LMW) fractions of NOM are separated in less from solution[17–19]. The residual organic matter in the solution is abandoned after coagulation is done as pretreatment[20,21]. The trihalomethanes, halo acetic acids are important constituents of DBP. These are mutagenic, carcinogenic and affects harmful toxicity on human cell line[11,17,22,23]. NOM composed with different organic molecular substances generally the hydrophilic and low molecular weight (LMW) fractions that cannot easily remove by the coagulation. On the other hand, the hydrophobic and high molecular weight (HMW) compounds are easily removed by different physicochemical methods, like coagulation-flocculation, from the water[17,24,25]. Thus, LMW and hydrophilic components dominate the residual organic matter after coagulation[26,27].

To neutralize negative charge of TOC as well as suspended colloidal particles electrocoagulation (EC) efficiently used as pretreatment for different water treatment[28–33]. The removal of DBPs' from water treatment was hindered by the major suspended colloidal particles. At the same time EC is helpful for removal of certain proposition of DOC from contaminated water[34–37]. EC is a process that where coagulants (aluminum, iron) are dosed by anodic dissolution of electrode materials by application of direct current (DC) potential. The removal efficiency of TOC is strongly dependent on the current density (i) and charge loading (q)[38]. Current density may be defined as the amount of current passing through per unit of the electrode area ($i = I/a$, where 'I' = current, amp; 'a' = active electrode area, cm^2). The charge loading is defined as the amount of charge on loaded per unit volume of water ($q = C/V$, 'C' = charge = $i \times t$, coulomb; V = volume of water). The literature reported that with increasing both current density and charge loading, removal of TOC get increased[39–43]. The investigators did not point out to the fact that the two factors are correlated and change of one factor could have modified the other and the main factor effect may be reported erroneously.

Thus, this study was conducted to establish a relationship between the effect of current density and charge loading to remove TOC from a synthetic sample during EC.

Materials and methods

Reagents:

Total organic carbon (TOC) powder was obtained from Sigma-Aldrich to prepare proper sample of organic contaminant sample. The electrode arrangement is made by aluminum sheet (0.5 cm thick) was commercially available and cut into the electrodes. Sodium chloride (NaCl, Merck) @ 20 mg/L was in addition to increase the electrical conductivity of the samples. And was bought from Merck, Germany (Darmstadt). A 32V AC-DC converter (PSD3005, Scientific Mes-Technik Pvt. Ltd., India) is used for EC. The batch EC experiments were done in the laboratory in 1.5 liters capacity Borosil glass jar with magnetic stirrer. The electrode gap was maintained at 2 mm. The active electrode area was maintained at (8×6) cm^2. TOC is maintained as 2.307 mg/L and adding 20 mg/L NaCl solution in a reactor to increasing conductivity into solution. TOC was measured by TOC analyzer (Vario TOC cube, Germany). The effect of variation of a dose of coagulant is determined from the amount of aluminum dissolved into water by EC and was calculated by Faraday's law. The effect of current density was measured by varying the current value through the same electrode area. A schematic diagram of the set-up is given in Fig. 1.

In this study the removal of TOC was studied at two different conditions, namely: (1) The effect of current density of a varying electrode area and (2) the effect of current density through the constant electrode area. The first condition was investigated by varying the effective electrode area and passing a constant charge loading of 36 C/L through the water

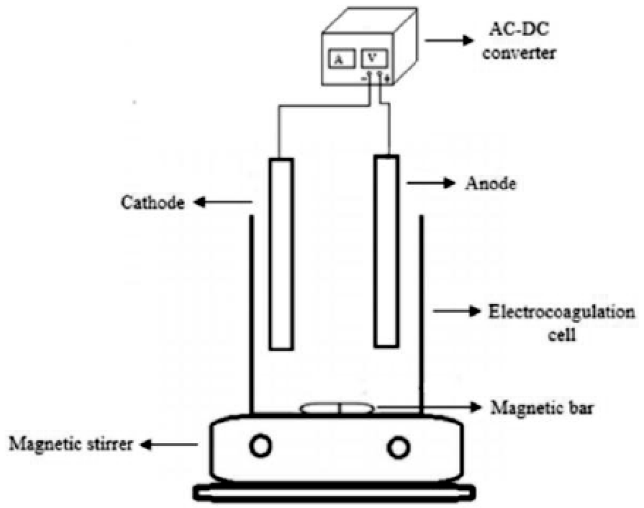

Fig. 1. Schematic diagram of experimental set-up for electrocoagulation system.

sample. The different cross-sectional areas are taken as 6, 12, 18, 24, 30, 36 and 42 cm^2 respectively and the correspondingly voltage was set for these cases are 3.8, 5.5, 8.9, 13.1, 17.2, 23.3 and 28.1 volt respectively. A constant charge loading 13.5 C/L was maintained. The second condition was investigated by fixing the electrode area at (8 cm × 6 cm = 48 cm^2) and the current density was studied by varying the time of EC while charge loading was kept constant at 13.5 C/L. This constant charge loading was maintained by the constant charge of 32 coulomb through the submerged electrodes.

Results and discussion

Effect of current density (A/cm^2):

The corresponding effect of current density on removal of TOC is shown in Fig. 2. It is clear that with increasing the current density, removal of TOC is decreased. Generally, the different authors stated that the positive effect of current density on the removal efficiency of different contaminants[2,39–42]. The positive effects on the removal efficiency is apparently showing due to the effect of varying charge loading and the effect of this important phenomenon was sometime is ignored[30,44].

From another perspective of the study the effect of current density was studied by varying the electrode area while charge loading was kept constant at a value of 13.5 C/L. This was achieved by a constant current value of 0.15 amp over 1.5 min time interval through different electrode area. The same trend (i.e. less removal over higher current den-

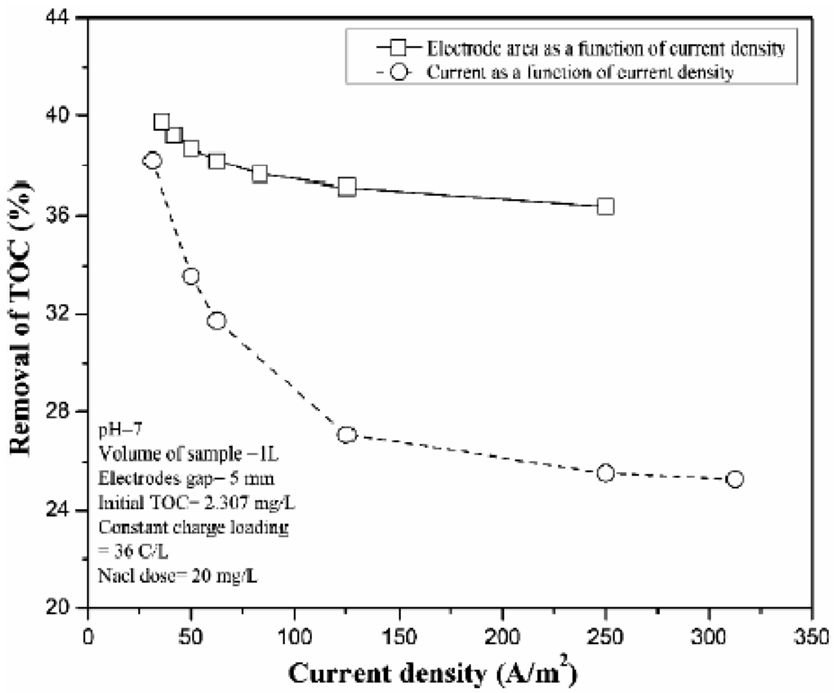

Fig. 2. The effect of current density for the removal of TOC (%).

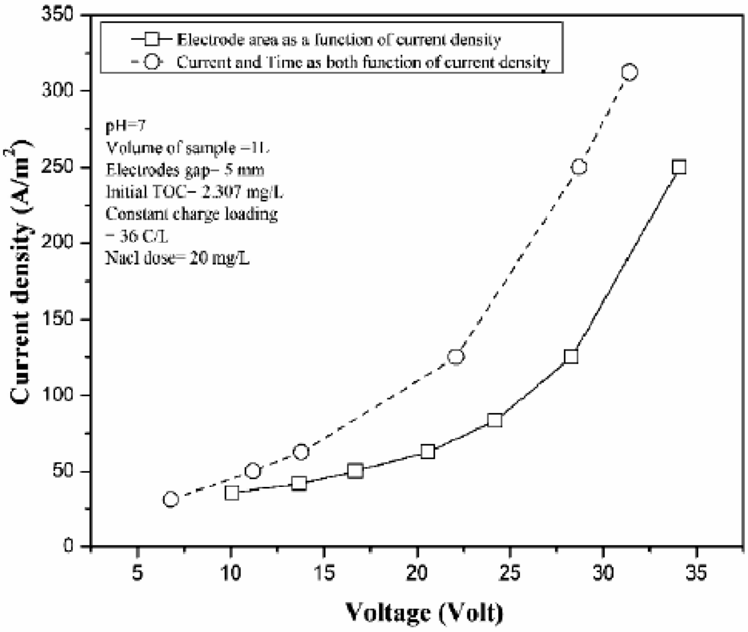

Fig. 3. The relation between voltage vs current density.

sity) is also observed in second case. However, when the current densities were varied by changing the electrode area, apparently higher potential was required to maintain a constant current of 0.15 A. In first case, to keep a constant current of 0.15 A through varying electrode area, the voltages were changed to 54.8, 50.2, 44.6, 38.8, 31.1, 24.6, 19.8 volt respectively. In the second case, a constant electrode area of (8×6) cm^2 and with a constant charge loading of 32 C/L. A plot of the comparative corresponding potential vs current density is given in Fig. 3.

The lower removal of TOC at higher current densities for a constant charge loading is due to the fact that with increased current densities, electrode potentials also get increased. Thus, when the electrode potential continued to increase beyond the Standard potential of the electrode material (1.662 volt for aluminium), some other side reactions (water splitting, deposition of other metals at cathode etc.) might also occurred. These side reactions reduce the current efficiency to produce equivalent amount of aluminium from anode that could have been obtained according to Faraday's law and subsequently showed lower removal of TOC. Fig. 3 corroborates the same electrochemical principle for removal of TOC[45].

This phenomenon influenced a portion of energy in EC is decapitated with the increasing of current density. For this reason, the loss of dose of coagulant is decreased and eventually the removal of TOC gets also decreased with the raising current density[45,46]. Therefore, it can be emphasized that the over voltage beyond the ORP of anodic electrode material during EC influence the metal (aluminum) precipitation[45,47].

Effect of charge loading (C/L):

Charge loading (C/L) is defined as the amount of charge passed through the unit volume of water. The effect of charge loading for removal of TOC is shown in Fig. 4.

It was clear from the Fig. 4 that, with the increment of the charge loading, the removal rate of TOC is increased in different extent[40–42]. In this experiment, the most remarkable change of removal of TOC was against the time. This is a very important aspect that slight variation in time of EC is influenced the generation of coagulant dose from metallic electrodes over the variation of current. But variation of passing of current is impacted very much at initial stage but after the generation of sufficient positive coagulant ions in the water, the removal of TOC is followed the uniform rate with the further increment of the charge loading. The change of volume of sample of water is inversely affected the removal of TOC from water. This is happening due to reduce the nega-

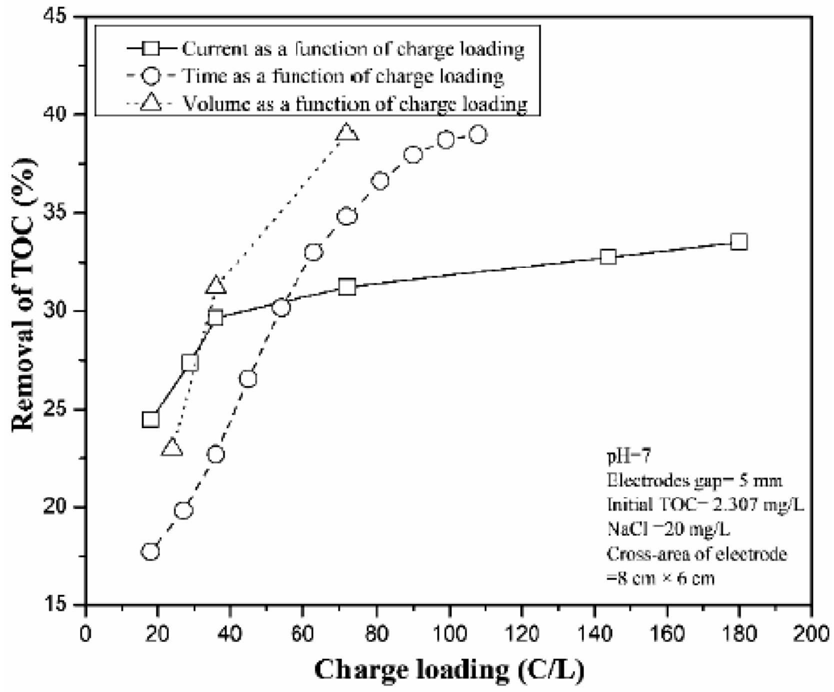

Fig. 4. The effect of charge loading for the removal of TOC (%).

tively charged TOC in the water easily charge neutralized and get settled out from the water sample. Similar results are also reported by other researchers[40–42].

To increase the charge loading by the variation of the time and current of EC are greatly increment of the voltage between electrodes is shown in Fig. 5. Because, this higher

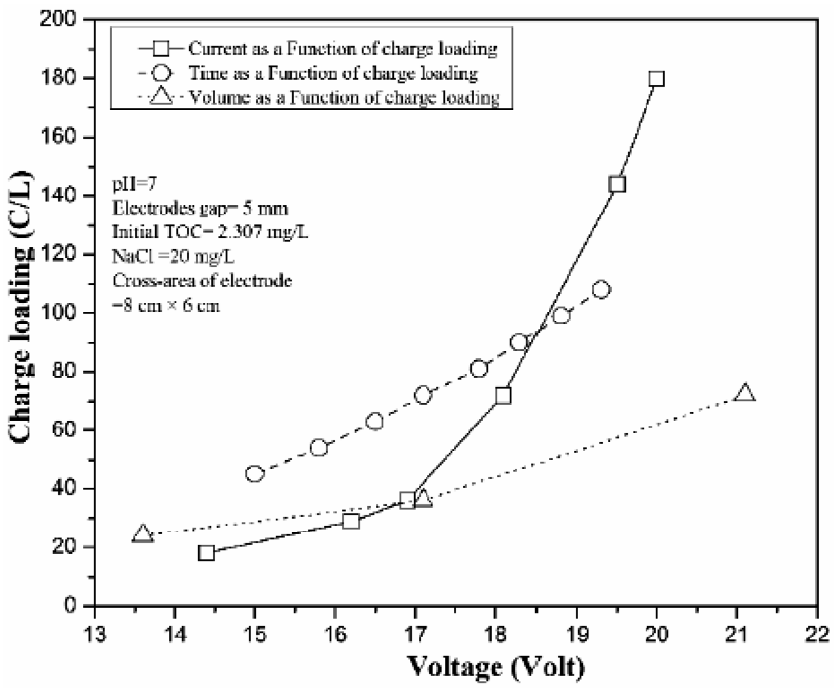

Fig. 5. Relation between voltage vs charge loading.

charge loading is required the higher voltage difference between electrodes and some unnecessary phenomenon such as spitting of water and fast passivation of cathode material are occurred. But for the change of charge loading by reducing the volume of water sample is inversely affected the voltage passing through the electrodes. Due less concentration of negative particles the sufficient charge loading is available in lower voltage range[45–47].

Conclusions

Most of the researchers reported that removal of TOC was increased by the increasing the current density. However, in this study it was the uncommonly reported that by the increasing the current density, removal of TOC was decreased for a constant charge loading. This contradictory report is due to the fact that, other researchers reported the effect of current density, while varying the charge loading also. So, the effect of current density is supposed to be studied in such a way that charge loading did not vary.

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