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Full Length Article

Solar powered Electrocoagulation system for municipal wastewater treatment

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ABSTRACT

In India, the living standard is getting upgraded with the development of the economy. This leads to consequent increase in the generation of wastewater causing damage to the environment in various aspects. The Electrocoagulation (EC) process has attracted a great deal of attention in treating various wastewaters because of its versatility and environmental compatibility. The present study was conducted to investigate the applicability of the EC technique in continuous mode for the treatment of Municipal wastewater (MWW) by using solar power through batteries. The solar powered EC is found to be appropriate as sole unit process to treat municipal wastewater. The effects of operating parameters such as current density (8–64 A/m^2) and detention time (4–24 min) on chemical oxygen demand (COD), turbidity and total dissolved solids (TDS) removal were studied. The optimum conditions were determined as 40 A/m^2 and 20 min by monitoring zeta potential (ζ) of the effluent. At the optimum conditions, removal efficiencies for COD (92.01%), turbidity (93.97%), and TDS (49.78%) were observed.

1. Introduction

Wastewater is the liquid end-product of municipal, agricultural, and industrial activity. Municipal Wastewater is the water that emerges after fresh water is used by human beings for domestic and commercial use. The municipal wastewater consists of floating materials, settable solids, organic and inorganic solids, oil, dissolved gases, and microorganisms as well as chemical oxygen demand (COD). All water pollutants have different characteristics, imposing separate threats for human health and their removal. Wastewater treatment plants are devoted to removing most of the pollutants while delivering water with little or no risk back in the stream, river, lake, groundwater, or industrial reuse. In general, domestic wastewater is one of the largest pollution sources due to its volume and concentration. So, it has the potential to cause severe water pollution. Hence, municipal wastewater must be treated and reused in an environmentally sound manner before it is discarded.

Wastewater treatment technologies are categorized into three major groups: Physical, chemical and biological processes. Examples of unit operations from each category are illustrated in Table 1. A typical wastewater treatment plant consists of a combination of physical, chemical and biological unit operations to target the removal of different constituents/pollutants. Physical unit operations depend purely on the physical separation of pollutants from wastewater without causing a significant change in the chemical or biological characteristics of the treated water.

Chemical processes are referred to as additive processes, as they require the addition of chemicals to react with the desired contaminants and remove it. The additive nature of chemical processes makes them less attractive compared to other processes as they increase the net dissolved constituents in wastewater and render it impractical to reuse in other applications. Biological unit processes utilize microorganisms for the biodegradation of contaminants in wastewater, and the main aim of these processes is to reduce the organic content and nutrients in wastewater. Biological units are generally classified into aerobic, anaerobic or facultative depending on the availability of dissolved oxygen in wastewater. Among physicochemical processes, electrochemical technologies have received great attention for their effectiveness in treating different types of wastewater with different electrode material and configuration [1,2]. Other than the above-mentioned processes promising, relatively new technologies that utilize the concepts of electrochemistry are also available such as electrocoagulation, electro oxidation, and electro floatation. The EC process has attracted great attention as one of the electrochemical technologies in wastewater treatment. [3–7].

At present, EC has drawn considerable attention, being a simple,

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Table 1
Classification of typical unit operations in wastewater treatment plants.

Physical processes	Chemical processes	Biological processes
Screening	Coagulation/ Flocculation	Trickling filters
Floatation	Chlorination	Aerated lagoons
Filtration	Adsorption	Activated sludge
Sedimentation	Ion exchange	Rotating biological contactors

(Source: Moussa et al., (2016).)

efficient and eco-friendly process. The EC process has many advantages such as simple equipment, easy operation, a shortened reactive detention time, no chemical additions, and decreased amount of sludge, which sediments rapidly. Several authors applied batch as well as continuous mode EC process to remove COD, turbidity, BOD and TSS from MWW. According to Marmanis et al., higher removal of pollutants is achieved at higher current densities and lower flow rates with higher energy consumption. In the EC process, generally iron (Fe) or aluminium (Al) electrodes are used, and at optimum conditions, removal efficiencies by Al are found to be higher than that of Fe [1,8]. Studies have been done successfully for Solar powered Electrocoagulation (SPEC) system for remote Australian communities to treat the water and wastewater [9] and phosphate removal from landscape water by SPEC using DC supply directly from photo-voltaic (PV) panel [10]. The environmental impact induced by the use of solar energy is minimal and this renders the solar powered EC process environmentally attractive. PV panels are an excellent choice for remote water treatment applications due to long life, modularity, low maintenance, and low noise. [11].

In remote communities the operation of such EC facilities may be limited due to the absence or insufficiency of electricity. Solar or photovoltaic (PV) energy is the ideal source of energy to overcome this problem.

The electrode material used in EC process is generally aluminium.

The main reactions are as follows

$$\text{Anode: } Al(s) \rightarrow Al^{3+} + 3e^{-} \tag{1}$$

$$\text{Cathode: } 3H_2O + 3e^{-} \rightarrow 1.5\,H_2(g) + 3OH^{-} \tag{2}$$

Al^{3+} and OH^{-} ions generated by electrode reactions (1) and (2) react to form various monomeric species which finally transform into $Al(OH)_3(s)$ according to complex precipitation kinetics:

$$Al^{3+} + 3H_2O \rightarrow Al(OH)_3^{+} + 3H^{+} \tag{3}$$

Freshly formed amorphous $Al(OH)_3$ (s) "sweep flocs" exhibit large surface areas which are beneficial for a rapid adsorption of soluble organic compounds and for trapping colloidal particles. Finally, these flocs are removed easily from the aqueous medium by sedimentation and flotation induced by the H_2 bubbles generated at the cathode [12,13], which is referred to as electro-flotation. The removal mechanisms in EC may involve oxidation, reduction, decomposition, deposition, coagulation, absorption, adsorption, precipitation, and flotation. SPEC cell characterized by simpler electrode geometry is reported in earlier works [14,15].

Our main objective was to study the applicability of continuous mode solar powered EC for the removal of pollutants from Municipal wastewater. The vertical up flow and down flow of wastewater is used in EC reactor whereas solar powered DC supply through batteries is used for EC experiments. Experiments were conducted to examine the effects of wastewater operating parameters, such as current density and detention time on removal efficiency of COD, turbidity, and TDS to optimize the operating conditions of SPEC process pursuing maximum removal of pollutants.

Table 2
Initial characterization of MWW.

Parameter	Value (±)
pH	7 ± 0.5
COD (mg/L)	260 ± 100
Turbidity (NTU)	60 ± 30
Conductivity (ms/cm)	2.4 ± 0.3
TDS (mg/L)	1300 ± 100

2. Materials and methods

2.1. Wastewater

In this study, municipal wastewater (MWW) is collected from sewer at 100 feet road, Sangli, Maharashtra, India. Grab sampling method is used for sampling. The collected wastewater was stored in tank and settled wastewater was used. The characterizations of MWW are presented through the average values and ± variation (Table 2).

2.2. Experimental setup

Electrocoagulation was carried out in an EC cell made of acrylic glass with dimensions of 120 mm (width) × 150 mm (length) × 92 mm (height) having net capacity volume of 1.66 L (Fig. 1). The unit consisted of six aluminium electrode plates; the 3 electrode plates are intended to act as anodes whereas, the other 3 electrode plates are to function as cathodes. The plates acting as anodes and cathodes are arranged alternatively having an inter-electrode distance of 1 cm. Washing of the electrode plates is easier as the plates are removable. The electrodes are punched alternatively at top and bottom edge for allowing the up flow and down flow of wastewater. The effective area of electrode is 0.0210 m^2 and has effective volume of one litre. The electrodes are connected in parallel connection to charge controller through batteries.

The solar photovoltaic module (Sova solar, SS60P), charge controller and batteries are procured from Dama global services, Sangli, Maharashtra, India. It consists of 2 PV panels of 60 W capacity each, MPPT charge controller having 12 V-25A capacity and 2 SMF batteries having capacity of 12V-26A each.

2.3. Experimental procedure

The EC experiments were carried out on MWW samples, in continuous mode. Each sample was feed to the EC unit through feed tank with predetermined flow rates to avail detention times of 4–24 min. For every detention time, different current densities varying between 8–64 A/m^2 are applied. After the EC process, the effluent leaving the EC unit was drawn in the glass beaker and was provided with detention time of 30 min. The settled sample was tested for usual characteristics.

The flow rate is calculated by, $Q = \frac{v}{t}$

where Q is the flow rate (L/h), t is the detention time (min), $v$is the volume of water treated (L).

The electrodes are removed from EC unit and washed neatly with tap water, prior and subsequent to every run. Then electrodes are placed back in the unit and HCl solution (5% v/v) is poured and kept in the unit for 20 min. Then the unit and electrodes were again washed with water neatly (see Table 3.).

2.4. Analytical method

The samples for influent and effluent of the lab treatment unit are