Journal of Environmental Management 204 (2017) 75–81

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Electrocoagulation treatment of raw landfill leachate using iron-based electrodes: Effects of process parameters and optimization

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ARTICLE INFO

Article history:
Received 7 June 2017
Received in revised form
9 August 2017
Accepted 17 August 2017

Keywords:
Electrocoagulation
Landfill leachate
Process parameters
Response surface methodology
Optimization

ABSTRACT

The main problem of landfill leachate is its diverse composition comprising many persistent organic pollutants which must be removed before being discharge into the environment. This study investigated the treatment of raw landfill leachate using electrocoagulation process. An electrocoagulation system was designed with iron as both the anode and cathode. The effects of inter-electrode distance, initial pH and electrolyte concentration on colour and COD removals were investigated. All these factors were found to have significant effects on the colour removal. On the other hand, electrolyte concentration was the most significant parameter affecting the COD removal. Numerical optimization was also conducted to obtain the optimum process performance. Under optimum conditions (initial pH: 7.73, inter-electrode distance: 1.16 cm, and electrolyte concentration (NaCl): 2.00 g/L), the process could remove up to 82.7% colour and 45.1% COD. The process can be applied as a pre-treatment for raw leachates before applying other appropriate treatment technologies.

1. Introduction

The rapid increase in population and urbanization have led to the increased generation of solid waste worldwide, prompting concern for environmental protection and sustainability (Azni, 2009). Although approaches such as reuse and recycle are being adopted to reduce the amount of solid waste, landfilling remains the dominant method for the disposal of solid waste in many countries (Norkhadijah and Latifah Abd. Manaf, 2013). One of the major issues with landfill is the generation of leachate which must be properly managed to prevent environmental pollution. Leachates poses hazard to the environment since it may contain various pollutants such as persistent organic pollutants (POPs), heavy metals and other recalcitrant organic pollutants. Thus, leachate treatment is quite challenging due to its complex nature (Labanowski et al., 2010). The characteristics of leachate will depend largely on the composition of the solid waste in the landfill (Brennan et al., 2016). Environmental factors like climatic conditions and hydrology could also have influence on the quality and quantity of the leachate. In addition, landfill age, cover design and operational activities could change the properties of the produced leachate (Umar et al., 2010). Thus, the management of leachate can be daunting since landfill can continue to generate leachate for many years. Since the leachate must be continuously collected and disposed, proper treatment is necessary before discharging to the environment.

The selection of treatment method is mainly based on the composition and properties of the landfill leachate. Various treatment methods such as aerobic, anaerobic, flotation, coagulation–flocculation, chemical precipitation, adsorption, and air stripping have been used for leachate treatment (Renou et al., 2008; Thompson et al., 2001). Although some of these methods are economical and easy to maintain, they possess some drawbacks which have hindered their applications in leachate treatment (Jeworski and Heinzle, 2000). Coagulation is considered an economical way to treat leachate through the use of chemicals such as alum and other compounds with coagulating effects. These chemicals facilitate the flocculation and coagulation of the particles, leading to easier removal via sedimentation. However, issues such as possible adverse effects of the chemicals, production of secondary pollutants and the cost of chemicals are viewed as

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http://dx.doi.org/10.1016/j.jenvman.2017.08.028
0301-4797/

drawbacks of chemical coagulation process (Freitas et al., 2015).

Recently, the use of electro-assisted coagulation or electrocoagulation (EC) for wastewater treatment has gain popularity. In EC, differences in electric potentials are used to generate coagulants which can remove colour, suspended and dissolved particles in wastewater (Irdemez et al., 2006). The basic reactions that occurs in an EC cell are described in Equations (1)–(3) (Dia et al., 2017). EC has been applied successfully for the treatment of textile dyes (Song et al., 2007), biodiesel wastewater (Chavalparit and Ongwandee, 2009), pharmaceutical wastewater (Farhadi et al., 2012), oil tanning effluent (Maha Lakshmi and Sivashanmugam, 2013), industrial wastewater (García-García et al., 2015), pretreated coke wastewater (Ozyonar and Karagozoglu, 2015), and heavy metals (You and Han, 2016). EC has gained significant attention from many researchers owing to its advantages such as reduced sludge production as compared to chemical coagulation, no requirement for external chemical coagulants, ease of operation, short operating time, and low capital and operating costs (Emamjomeh and Sivakumar, 2009; Zhao et al., 2014).

At the Anode: $$M_{(S)} \rightarrow M^{n+}_{(aq)} + ne^- \quad (1)$$

At the cathode: $$2H_2O + 2e^- \rightarrow 2OH^- + H_2 \quad (2)$$

In the solution: $$M^{n+}_{(aq)} + nOH^- \rightarrow M(OH)_{n(s)} \quad (3)$$

Several studies on the use of coagulation for leachate treatment have been reported. These studies have mainly focused on the use of chemicals such as $FeCl_3$ (Dolar et al., 2016), $FeSO_4$ (Shu et al., 2016), polyaluminum chloride (PACl) (Long et al., 2017) and other compounds to remove contaminants from the leachate. For example, Oloibiri et al. (2015) compared the efficiency of $FeCl_3$ and PACl as coagulants in the treatment of leachate. $FeCl_3$ was effective in removing 66% COD at a dose of 1 mg $FeCl_3$/mg COD whereas about 44% COD was removed when PACl was used at the same dose. In another coagulation study for leachate treatment, Bakraouy et al. (2017) used 4.4 g $FeCl_3$/L and achieved maximum colour, COD and turbidity removals of 95%, 88% and 73%, respectively. However, because of high chemical consumption when using chemical coagulants in leachate treatment, attention is being shifted to EC as a better alternative. Dia et al. (2017) investigated the electrocoagulation of bio-filtered landfill leachate and were able to removed 70% and 65% COD using aluminium and iron electrode, respectively. Earlier, Oumar et al. (2016) had reported the EC of biologically-treated leachate using magnesium-based anode and achieved 53% COD and 85% colour removals. From the literature review, it was evident that the few studies on leachate treatment using EC have largely focused on the treatment performance, with less emphasis on the process parameters and their effects on pollutants removal. Since EC is still conducted at laboratory scale, parametric studies and process optimization are necessary for scale-up and process development.

Thus, the objective of this study is to investigate the effects of process parameters on the treatment of landfill leachate using EC with iron as the electrodes. Process parameters, such as initial pH, electrolyte concentration, and inter-electrode distance can significantly affect the performance of EC treatment. These parameters are therefore studied and optimized in this study. Response surface methodology (RSM) was employed to study and optimize these parameters. RSM is a commonly used statistical tool where certain variables influence some response(s), and optimization is therefore desired. The major advantage of RSM is that, in contrast to one-factor-at-a-time study, fewer number of experiments are required and the interaction between variable can be investigated (Lambropoulou et al., 2017).

2. Methodology

2.1. Chemicals

Sulfuric Acid (96% purity, AR Grade, Fisher Scientific) and Sodium Hydroxide (R & M Chemicals) were used for pH adjustment. Hydrochloric acid (37% purity, AR Grade, Eriendemann Schmidt) was used to clean the electrodes. Sodium chloride (R & M Chemicals) was used as electrolyte. COD Cell Test (300–3500 mg/l, Spectroquant-Merck) was used to measure the oxygen required to oxidize soluble and particulate organic matters in the leachate.

2.2. Sample collection and characterization

Raw landfill leachate was collected from Jeram Sanitary Landfill (JSL) located at Tuan Mee Estate, Jeram, Kuala Selangor, Selangor, Malaysia and used without pre-treatment. JSL is an active landfill that commenced operation in 2007, receiving 95% of domestic waste and 5% of other waste with the current capacity of 2500 tonne per day. The collected leachate was analysed and stored at 4 °C throughout the experiments. COD and colour removals of treated effluent was measured using Spectrophotometer (Spectroquant Pharo 300). pH measurement was performed with a pH meter (CyberScan pH 300, EUTECH Instruments). Final voltage was measured using a multimeter (MultiMaster 570A True RMS, EXTECH Instruments).

2.3. Electrocoagulation system setup

The basic EC setup used in this work is presented in Fig. 1. It consists of iron sheets as anode and cathode (42 cm^2 effective surface area), submerged into 500 mL leachate solution in a 600-mL beaker. The reaction mixture was stirred using magnetic stirrer (WiseStir MS-20D) and magnetic stirring bar at 100 rpm. DC regulated power supply (EXTECH-382213) was used to supply 1.0 A of current to the electrochemical system for 60 min.

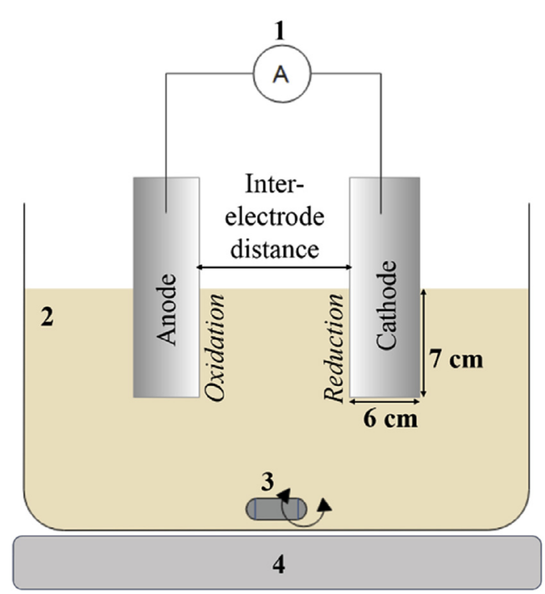

Fig. 1. Schematic diagram of EC setup: (1) DC power supply, (2) diluted landfill leachate, (3) magnetic bar and (4) magnetic stirrer.