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Research article

Coupling biofiltration process and electrocoagulation using magnesium-based anode for the treatment of landfill leachate

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ABSTRACT

In this research paper, a combination of biofiltration (BF) and electrocoagulation (EC) processes was used for the treatment of sanitary landfill leachate. Landfill leachate is often characterized by the presence of refractory organic compounds (BOD/COD < 0.13). BF process was used as secondary treatment to remove effectively ammonia nitrogen (N-NH_4 removal of 94%), BOD (94% removed), turbidity (95% removed) and phosphorus (more than 98% removed). Subsequently, EC process using magnesium-based anode was used as tertiary treatment. The best performances of COD and color removal from landfill leachate were obtained by applying a current density of 10 mA/cm^2 through 30 min of treatment. The COD removal reached 53%, whereas 85% of color removal was recorded. It has been proved that the alkalinity had a negative effect on COD removal during EC treatment. COD removal efficiencies of 52%, 41% and 27% were recorded in the presence of 1.0, 2.0 and 3.0 g/L of sodium bicarbonate ($NaHCO_3$), respectively. Hydroxide ions produced at the cathode electrode reacted with the bicarbonate ions to form carbonates. The presence of bicarbonates in solution hampered the increase in pH, so that the precipitation of magnesium hydroxides could not take place to effectively remove organic pollutants.

1. Introduction

Landfilling is one of the most common ways to manage municipal solid wastes. However, this technic can be related with some environmental issues if the landfill is not monitored properly. For example, percolation of rainwater into the landfill leads to the production of an effluent polluted with organic, inorganic and microbial materials called landfill leachate that has the potential threat for both groundwater, and surface water (Lema et al., 1988).

Landfill leachate characteristics can be defined by several parameters: operating modes (degree of compaction, height waste etc.), nature of waste, local climate, geological features of the site, age of landfill etc. Among these factors, age of landfill have a major importance on landfill leachate composition. Accordingly, landfill leachate could be divided into three types: “young”, “intermediary” and “mature” or stabilized landfill leachate (Renou et al., 2008). The young landfill leachates having an age up to 5 years, are characterized by high concentration of biodegradable organic compounds (Harmsen, 1983). By comparison, mature landfill leachate having more than ten years are characterized by refractory organic compounds (Ehrig, 1989).

Biological processes are often used to treat young landfill leachate due to their biodegradability. According to the literature, many biological processes such as aerated lagoon (Robinson and Grantham, 1988), activated sludge (Kettunen et al., 1996), attached biomass (Li et al., 2010; Martienssen et al., 1995) membrane bioreactor (MBR) (Ahmed and Lan, 2012) sequencing batch reactor (SBR) (Dollerer and Wilderer, 1996) and others had been applied for landfill leachate treatment. Among biological processes, biofiltration technology has many advantages such as low footprint and good resistance to the variation of volumetric loading (Galvez et al., 2009; Pujol et al., 1994; Xie et al., 2010). The materials used as media could be categorized as inorganic (plastic, pozzolan, glass bead, expanded clay etc.) and organic (peat, wood chips, compost,

List of acronyms: BF, biofiltration; BODs, biochemical oxygen demand; COD, chemical oxygen demand; EC, electrocoagulation; LL, landfill leachate; min, minutes; ne, number of exchanged electrons.

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activated carbon etc.). Peat based biofilters have been founding increased use, as they showed high efficiency for biodegradable organic carbon and nitrogen removal (Champagne and Khalekuzzaman, 2014; Heavey, 2003; Kangsepp and Mathiasson, 2009; Kõiv et al., 2009), due to its a high specific surface for microorganisms (Buelna et al., 2008; Couillard, 1994). In addition, the presence of some chemicals groups on its surface (alcohol, aldehydes, ketones, acids and ethers) could be involved in the depollution process by interacting with pollutants throughout adsorption, complexation, chelation and ions exchanges reactions (Couillard, 1994).

Although the effectiveness of biological systems is well known for biodegradable landfill leachate, biological methods do not generally provide the necessary quality of treatment for wastes containing refractory organic pollutants (Galvez et al., 2009). For example, humic substances contained in landfill leachate are difficult to oxidize biologically.

To tackle this issue, combined treatment methods have been finding increased use, biological treatment followed by physical-chemical treatment. Physical chemical process is often employed as tertiary treatment after biological treatment (Galvez et al., 2009). Different types of physicochemical, electrochemical, membrane filtration and advanced oxidative processes have been integrated with biological processes. Among these technologies, electrocoagulation process is a promising technique that can be coupled with biological process in order to improve the effectiveness of landfill leachate treatment. The principle of EC is to generate, in-situ, coagulants using an electrical potential difference. These coagulants can agglomerate colloidal suspensions and form insoluble metal hydroxides on which organic matter could be adsorbed.

Even though, the combination of biological and electrocoagulation processes for landfill leachate treatment has been rarely reported in the literature, however, it has been tested for the treatment of different types of effluents such as bleaching effluent (Antony and Natesan, 2012), grey water (Bani-Melhem and Smith, 2012), industrial effluents (Moises et al., 2010), municipal wastewater (Stafford et al., 2014) and synthetic wastewater (Yu et al., 2006). In these studies, satisfactory results were obtained in terms of organic matters, suspended solids and phosphorus removal.

The objective of this research project was to study the feasibility of coupling a biological process (biofiltration) with an electrochemical process (electrocoagulation) for the treatment of "mature" landfill leachate. Hence, the biological system was placed before the electrochemical process. The efficiency of biofiltration in terms of nitrogen, organic matters and turbidity removal was investigated, whereas for the electrochemical treatment, the influence of current density, treatment time and alkalinity on residual COD removal was considered.

2. Materials and methods

2.1. Landfill leachate

Landfill leachates used throughout this study were taken from a municipal landfill site of Saint-Rosaire's City, Québec, Canada. This landfill area is 44 ha having a landfilling capacity of 65,000 tons/year. The annual flow rate of leachate production is around 100 m^3/j. Landfill leachates were stored in three open sky tanks, each one having 2750 m^3 of capacity. The sampling was taken from the storage tanks with the average frequency of three weeks. Samples were collected in polypropylene buckets and kept at 4 °C before use.

2.2. Biofiltration experimental unit

A PVC column was used as biofilter unit with a dimension of 2 m (height) x 0.2 m (inside diameter). The biofilter system used indigenous microflora bacteria fixed on an organic support mainly comprised of peat and wood shavings. The filter media was arranged vertically as follows (from the top to the bottom): 10 cm of wood ships, 30 cm of a mixture of 80%(v/v) wood + 20%(v/v) peat + 5%(v/v) of calcite, 30 cm of wood ships, 90 cm of 80% (v/v) wood ships + 20% (v/v) peat + 5% (v/v) calcite. The calcite was added in the filter media in order to buffer the pH and to provide a mineral carbon source for autotrophic microorganisms. The landfill leachate was filtered by percolation. The biofilter acclimation was performed by gradually increasing the hydraulic loading rate inside the biofilter unit. Once the acclimation was completed, the inlet flow rate was set at around 5.3 L/d, corresponding to a hydraulic loading rate of 0.17 m^3/m^2/day. The column was aerated by injecting compressed air from the bottom with a flow rate of 5 l/min. The air was moistened through a hermetic water balloon before being injected in the column. It is worth noting that the pilot worked at room temperature (22 °C). The biofilter clogging was monitored by measuring every four days the output flow rate of the biofilter and checking regularly if there was appearance of stagnant liquid on the surface of the biofilter unit.

2.3. Electrochemical cell

A cylindrical electrolysis cell, having 1.5 L of capacity was used. This electrolytic unit was comprised of two concentrical electrodes (Fig. SM-1). The cylindrical anode electrode (79.8 cm length × 1.9 cm diameter) was made of alloy based magnesium having a working surface area of 476 cm^2. The hollow cylindrical cathode electrode (72 cm length and 5 cm inner diameter) was made of stainless steel (SS) and having a surface area of 1130 cm^2. The assays were carried out in a closed loop, depicted schematically in Fig. SM-1. A conical reservoir (to introduce wastewaters in the system), a centrifugal pump and the electrolytic cell constitute the loop. The electrochemical tests were conducted in a batch recirculation mode with a liquid flow entering in the top of the cell. The electrochemical cell was provided by E2Mextrix Inc, Sherbrooke, Québec, Canada. The electrochemical cell was operated under galvanostatic conditions. Current intensities were imposed by means of a DC power source, Xantrex XFR40-70 (Aca Tmetrix, Mississauga, ON, Canada) with a maximum current rating of 70 A at an open circuit potential of 40 V. Due to high conductivity of landfill leachate, no electrolyte salt was added during the EC process. 30 ml aliquot was taken from the reactor at different treatment time and then naturally settled down for at least one hour, and finally supernatant was collected for the analysis.

2.4. Analytical details

pH was measured by a pH meter (Accumet Excel XL25 – pH/mV/Temp/Ion Meter, Fisher Scientific Co) with a Cole-Palmer double junction electrode (Ag/AgCl reference). Turbidity was determined by a turbidimeter (2100N Laboratory Turbidimeter, EPA, 115 Vac, HACH). Chemical oxygen demand (COD) was measured by the colorimetric method (closed Reflux) certified by the APHA (APHA, 1998). Ammonia ($N\text{-}NH_4$) and *ortho*-phosphate ($P\text{-}PO_4$) concentrations were simultaneously analyzed by QuikChem method 10-107-06-2-B and QuikChem method 10-115-01-1-B respectively using Lachat Instrument. Samples of COD, NH_4 and PO_4 were acidified under pH 2 before analysis. Measurement of BOD_5 was carried out by an accredited laboratory (AGAT Laboratories, Quebec, Canada). BOD_5 was analyzed according to APHA standard method