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Review

Review on the electrochemical processes for the treatment of sanitary landfill leachates: Present and future

A. Fernandes*, M.J. Pacheco, L. Ciríaco, A. Lopes

FibEnTech/MTP Research Unit and Department of Chemistry, University of Beira Interior, 6201-001 Covilhã, Portugal

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ABSTRACT

Due to its properties and composition, sanitary landfill leachate is one of the major environmental problems concerning water pollution. The optimization of the leachate treatment, in order to fully reduce the negative impact on the environment, is a nowadays challenge. Advanced technologies for the treatment of sanitary landfill leachates have received increasing attention over the past decade. This paper presents a general review of efficient electrochemical technologies developed to decontaminate sanitary landfill leachates. An overview of the fundamental aspects of electrochemical methods, such as electrocoagulation, electro-Fenton and electrochemical oxidation, is provided and updated information on the application of these technologies to sanitary landfill leachates is given. The effect of the main process variables of these electrochemical technologies in the sanitary landfill leachates treatment effectiveness is discussed and a critical analysis of the prime benefits and drawbacks of its application is made.

Contents

1. Introduction

Population growth and new patterns of consumption have been leading to the production of huge amounts of municipal solid wastes that are usually discarded in sanitary landfills, since this is a relatively simple procedure with low cost [1]. However, as a result of the rainwater percolation through the wastes, extracting and bringing with it several pollutant materials, a very complex wastewater is produced, usually known as sanitary landfill leachate. Several types of pollutants can be found in the sanitary landfill leachates composition, such as all types of organic and inorganic compounds, some of them refractory and toxic, and heavy metals [1,2]. Due to its complex, recalcitrant and varied composition, sanitary landfill leachates represent a significant source of pollution, presenting an accumulative, threatening and detrimental effect to the survival of aquatic life forms and ecological balances [3]. An inadequate leachate management involves serious risks, particularly the contamination of water resources, at the surface and groundwater, and soils, and consequently, it may induce genome damage in the population that consumes the contaminated water [1–4].

Biological reactors, with nitrification/denitrification steps, followed by membrane technologies, are commonly used to treat sanitary landfill leachates. However, due to the variability in the quality and quantity of the leachate throughout the life span of the treatment plant, these conventional treatments may become ineffective. Thus, it is very important to apply reliable and

* Corresponding author. Tel.: +351 275 319 880; fax: +351 275 319 730.
E-mail address: annabelf@ubi.pt (A. Fernandes).

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Nomenclature

List of symbols

AN	Ammonia nitrogen
BDD	Boron-doped diamond
BOD	Biochemical oxygen demand
Carbon-PTFE	Carbon-polytetrafluoroethylene
CFD	Computational fluid dynamics
COD	Chemical oxygen demand
DOC	Dissolved organic carbon
DSA	Dimensionally stable anode
EC	Electrocoagulation
EF	Electro-Fenton
EO	Electrochemical oxidation
ICE	Instantaneous current efficiency
PCDD/Fs	Dibenzo-*p*-dioxins and dibenzofurans
RSM	Response surface methodology
SPR	Ternary Sn–Pd–Ru oxide coated titanium
TOC	Total organic carbon

effective treatment technologies, capable of deal with such complex effluents.

Electrochemical treatments have been showing high effectiveness in the elimination of persistent pollutants and several studies have described the application of these methods in the treatment of complex effluents [5–10]. In fact, electrochemical technologies provide several advantages, being the inherent advantage the environmental compatibility, since the main species involved in the oxidation process are electrons and oxidant agents produced in situ. Other advantages include the use of simple equipment, easy operation, robustness, versatility and amenability to automation [11,12]. Among the electrochemical technologies, the most studied for the treatment of sanitary landfill leachate are electrocoagulation (EC), electro-Fenton (EF) and electrochemical oxidation (EO). There are several reports describing the application of these technologies to leachates, as a single treatment, or combined with other methods. Photoassisted systems, like photoelectro-Fenton and photoelectrocatalysis, have also received great attention in the last years, but will not be discussed in this paper, since they are outside the scope of this review.

The aim of this paper is to present a general review of the most relevant applications of the electrochemical methods in the treatment of sanitary landfill leachates, to point out some scarcely studied aspects, whose development may contribute to the application of these technologies at an industrial scale, and to present the future perspectives for the application of the electrochemical processes in the treatment of effluents with high organic load. Fundamentals of EC, EF and EO technologies are briefly presented to better understand their advantages and limitations in the treatment of the sanitary landfill leachates.

2. Sanitary landfill leachate characteristics and environmental impacts

The composition of sanitary landfill leachates varies depending on landfills characteristics, such as: [13,14] the waste type received at the disposal site and its decomposition degree; the climatic variation during the waste disposal; the filling process regarding waste compaction, landfill cover and height of landfill layers; and the landfill environment – waste degradation phase, humidity, precipitation, temperature, etc. These aspects are interconnected and their combination contributes to the overall variance in the leachate quality and composition.

According to the age, the sanitary landfill can be classified as young (less than 5 years), medium age (5–10 years) and old (more than 10 years) [3]. As the landfill age increases, leachates parameters, such as chemical oxygen demand (COD), biochemical oxygen demand (BOD), BOD/COD ratio and pH vary considerably [3]. Fig. 1 represents the trend in the variation of the main parameters that characterize sanitary landfill leachates with the age of the sanitary landfill [3,7,13,15,16]. It can be seen that COD and BOD concentrations decrease as time proceeds and the leachate organic waste degradation goes through the successive aerobic, acetogenic, methanogenic and stabilization stages [13]. In fact, most of the biodegradable organic matter, which can be evaluated by BOD value, is decomposed in the stabilization process and therefore BOD/COD ratio decreases with time, because the non-biodegradable organic matter that contributes to the portion of COD will largely stay unchanged in this process [17]. On the contrary, pH increases with age [7]. In sum, leachates from young sanitary landfills are characterized by high COD concentrations (>10,000 mg L^{-1}) and BOD/COD ratios (0.5–1), whereas in old landfills leachates present COD concentrations below 4000 mg L^{-1} and BOD/COD ratios below 0.1 [3]. Besides the variation of the landfill leachates composition with the landfill age, it also varies from place to place, leading to huge fluctuations in the values of the most representative characterization parameters (Fig. 1). Apart from the represented parameters in Fig. 1, there are more than 200 compounds that have already been identified in sanitary landfill leachates, such as aromatic and halogenated compounds, phenols, pesticides and several heavy metals [1,2,14].

In addition to the organic load, ammonia nitrogen (AN) is of great environmental concern in landfill leachates [7]. It is released from the wastes, mainly by decomposition of proteins, and it has been found in leachates at concentrations ranged from 0.2 to 13,000 mg L^{-1} [13]. Ammonia nitrogen concentration does not have an obvious decreasing trend with time, except due to dilution effects, and may disrupt biological units for leachate treatment due to its toxicity. Therefore, AN has been identified as the most significant component in the leachate in a long term [15].

3. Electrochemical technologies for the treatment of sanitary landfill leachates

The electrochemical technologies are based on electron transfer between electrodes and the electrolytic solution, by applying an electric field between anode and cathode, made of specific materials, appropriate for each electrochemical technology. The applied current/potential difference provides the driving force necessary to promote the oxidation/reduction reactions of the solution' pollutants, contained in the electrochemical cell. The environmental compatibility, versatility and amenability of automation of these technologies [12], as well as the high effectiveness shown in the elimination of persistent pollutants [5–10], led to an increased number of experimental works.

In the subsections below, the fundamentals of electrocoagulation, electro-Fenton and electrochemical oxidation and the main results obtained from their application to sanitary landfill leachates treatment are presented.

3.1. Electrocoagulation

Electrocoagulation is a process that uses consumable electrodes to supply ions to the solution/suspension, allowing suspended, emulsified, or dissolved contaminants to form agglomerates. The coagulating ions are produced in situ and three different stages can be identified: [18] (i) formation of the coagulants by electrolytic oxidation of the "sacrificial electrode", (ii) destabilization