Chemical Engineering Journal 228 (2013) 455–467

Contents lists available at SciVerse ScienceDirect

Chemical Engineering Journal

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

Review

Three-dimensional electrochemical process for wastewater treatment: A general review

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HIGHLIGHTS

- Three-dimensional electrochemical process for environmental applications was reviewed.
- The conception, advantages, reactor and mechanisms of 3D electrode system were presented.
- The anode/cathode materials, particle electrode and catalysts utilized were summarized.
- Its applications for wastewater treatment and adsorbents regeneration were demonstrated.
- Main processes parameters were discussed and possible outlook was suggested.

ARTICLE INFO

Article history:
Received 30 January 2013
Received in revised form 6 May 2013
Accepted 11 May 2013
Available online 20 May 2013

Keywords:
Three-dimensional electrochemical process
Wastewater treatment
Particle electrode
Adsorbent regeneration
Degradation mechanism

ABSTRACT

Three-dimensional (3D) electrochemical process has been recognized as an effective method for wastewater treatment. In comparison to two-dimensional (2D) electrochemical process, the introduction of particle electrodes brings about higher specific surface area and shorter distance of mass transfer, which renders it more effective and promising for environmental applications. This paper presents a comprehensive review on the development and application of this process. The conception, advantages and basic mechanisms of 3D system is presented. Different kinds of electrode materials utilized in 3D reactor are systematically summarized, including anode and cathode materials, particle electrode materials and their catalysts. The structures of 3D reactor as well as the effect of important operating parameters are discussed, such as cell voltage, treatment time and pH values. Their applications in various wastewaters treatment and adsorbents regeneration are thoroughly reviewed. Finally the outlook of the process for future research is suggested.

Contents

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http://dx.doi.org/10.1016/j.cej.2013.05.033

1. Introduction

Widely distributed toxic substances, such as heavy metals, phenolic compounds, and other nonbiodegradable pollutants from some industrial wastewaters are considered to be harmful to humans and the environment [1]. In this context, conventional biological treatment does not always achieve satisfactory performance [2], also traditional physical–chemical processes are relatively expensive, ineffective or may lead to secondary pollution. Thus, how to remove these substances affordably and efficiently is an urgent challenge.

During the last two decades, electrochemical technologies have made great progress in wastewater treatment, especially for the bio-refractory substances abatement due to its high efficiency, environmental friendly and versatility [3–7]. In spite of these advantages, there are still some shortcomings limiting their industrial application, such as short lifetime of electrode materials and low current efficiency. Moreover, some intrinsic drawbacks such as mass transfer limitation, small space–time yield, low area–volume ratio and temperature increase during the process cannot be satisfactorily solved in conventional electrochemical reactor especially when the wastewater is of low conductivity.

The review of three-dimensional (3D) electrode or bed electrode provides an excellent solution to the disadvantages which limit the application of two-dimensional (2D) electrode [8]. Compared to 2D electrode, the addition of granular activated carbon (GAC) or metal particles may also enhance the conductivity and mass transfer or the adsorption of pollutants [9]. Also, the large specific surface areas of these particles can provide more reactive sites than 2D electrode for pollutants adsorption or even catalytic reactions [10,11], resulting in higher removal efficiency [12–15].

Since the emerging of 3D electrode, its development is relatively slower comparing with that of 2D system, but in recent years, it has attracted considerable attention in environmental protections. Its application extend from metal ions removal in early stage [16–20] to different kinds of wastewater, including dyes [13,14,21–23], oil refinery wastewater [9,15], phenolic compounds and derivatives [24–27], hydrocarbons and some other pollutants [28–32]. Unfortunately, to the best of our knowledge, there are almost no comprehensive reports on the review of 3D electrochemical process for environmental protections.

In this paper, a general review of 3D electrochemical process was presented, including its conception and advantages compared with those of 2D system, electrode selections, particle electrode characteristics, operating parameters and its application for various wastewaters treatment and adsorbent regeneration. Simultaneously, outlooks for future development are also suggested. It is expected that this review would draw more attention to this promising technology and help to gain knowledge and push forward to its development.

2. Three-dimensional electrochemical process

2.1. Definition

It is well recognized that 3D electrochemical process is established based on 2D electrochemical process with many similarities such as electrode materials and treatment processes, except the third electrode. It is also named particle electrode or bed electrode, is basically granular or fragmental materials which are filled between two counter electrodes. At an appropriate voltage, these particles will be polarized to form a large numbers of charged microelectrodes with one surface of which can be considered as anode while the other is charged the opposite. With the existence of particle electrodes, 3D electrochemical process shows a better performance than conventional 2D electrochemical system. In some cases, when the anode or cathode is three-dimensional, they also can be regarded as a kind of 3D reactor. Table 1 offers a general summarization on different performance between 3D and 2D system under similar conditions for different pollutants removal. It clearly verifies that the COD removal efficiency in 3D system is 10–50% higher than that in 2D system, demonstrating the advantages of 3D system sufficiently.