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Review

Review on electrical discharge plasma technology for wastewater remediation

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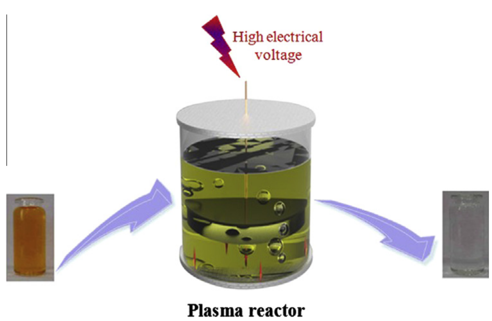
HIGHLIGHTS

- Various plasma reactors available for water remediation are addressed.
- Combination of plasma with catalysts for pollutant removal is reviewed.
- Some factors in pulsed electrical discharge are systematically discussed.
- Further researches and challenges for plasma technology are presented.

GRAPHICAL ABSTRACT

Electrical discharge plasma can be generated in a reactor with introducing high electrical voltage. After plasma treatment, wastewater can be remediated with fast treatment rate and environmental compatibility.



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ABSTRACT

As wastewater remediation becomes a global concern, the development of innovative advanced oxidation processes for wastewater treatment is still a major challenge. With regard to its fast removal rate and environmental compatibility, plasma technology is considered as a promising remediation technology for water remediation. The principles of electrical plasma with liquids for pollutant removal and the reactors of various electrical discharge types are outlined in this review. To improve energy efficiency, combination of plasma technology with catalysts has attracted significant attention. The present review is concerned about present understanding of the mechanisms involved in these combined processes. Further on, detailed discussions are given of the effects of various factors on the performance of pulsed electrical plasma technology in water treatment processes. Finally, special attention is paid to the future challenges of plasma technology utilized for industrial wastewater treatment.

Contents

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1. Introduction

Organic compounds as a major group of pollutants in wastewater are of concern worldwide due to their severe problems for the environment and human health [1]. Thus, in the cases of unavoidable pollutant emissions, these emerging compounds must be treated to satisfy the stringent water quality regulations before discharging into aquatic ecosystem.

Advanced oxidation processes (AOPs) are innovative tools that involve an introduction of energy (e.g., chemical, electrical and radiative) into the reaction zone to generate highly reactive species, especially hydroxyl radicals whose standard potentials are up to 2.8 V ($E^0_{OH^\cdot/H_2O}$) in acidic media [2]. Interest in the utilization of electrical plasma technology, as one of the AOPs, for organic pollutants removal has increased enormously, mainly because of environmental compatibility and high removal efficiency. The electrical discharge plasma technology leads to various physical and chemical effects, such as primary formation of oxidizing species: radicals ($H^\cdot$, $O^\cdot$, $OH^\cdot$) and molecules (H_2O_2, O_3, etc.), shockwave, ultraviolet light and electrohydraulic cavitation [3–5]. Consequently, plasma degradation process is generally regarded as a combined process of some other AOPs including ozonation, UV photolysis and pyrolysis, etc. and has the advantages of no demands on temperature and pressure, insensitive to contaminants and environmental friendliness.

Up to present, previous reviews involving plasma technology have covered in detail plasma chemistry and physics, mathematical modeling and its environmental applications, etc. [6–14]. In this review, the contribution focuses on a detailed review of plasma reactors available for water remediation, plasma-catalytic oxidation processes and the factors influencing plasma process as well as future researches of plasma technology for industrial scale application.

2. Plasma technology

2.1. Introduction to plasma

Plasma is a partially or fully ionized gas consisting of electrons, free radicals, ions and neutrals. And it can be produced by a variety of electrical discharges. All varieties of plasma systems are traditionally defined into two major categories, namely thermal and non-thermal, in terms of electronic density or temperature [4]. Thermal plasma (usually arc discharges, torches or radio frequency) is associated with sufficient energy introduced to allow plasma constituents to be in thermal equilibrium. While non-thermal plasma is obtained using less power (usually corona discharge, dielectric barrier discharge, gliding arc discharge, glow discharge and spark discharge), which is characterized by an energetic electron temperature much higher than that of the bulk-gas molecules. In this plasma, the energetic electrons can collide with background molecules (N_2, O_2, H_2O, etc.) producing secondary electrons, photons, ions and radicals [7].

2.2. Application of plasma for water treatment

Thermal plasma is sustained with introducing high electrical energy, so that a high flux of heat is created, which can be used in processing even the most recalcitrant wastes via thermal incineration processes [15]. As for non-thermal plasma, it does not express a local thermodynamic equilibrium, which, therefore, offers high selectivity and energy efficiency in plasma chemical reactions. In view of these facts, applications of atmospheric pressure electrical plasma technologies for water treatment attract the increasing interest and emerge as technological opportunities for the plasma community.

Based on the plasma-phase distribution, electrical discharges with liquids can be subdivided into three main groups, namely, electrical discharges above liquid surface, direct electrical liquid discharges and discharges in bubbles/vapor in liquids [5].

In the cases of electrical discharges above liquid surface, the plasma generation and gas phase breakdown above liquid surface are mostly similar to the gas electrical discharge due to their analogous breakdown strength in the atmospheric gas. But, as to electrical discharges above liquid surface with the liquid as an electrode, the existence of the liquid surface affects the physical aspects of the discharge, as well as the chemical processes occurring in the gas–liquid interface. The reason is that the discharge current is transported through the water electrode by ions which have a much smaller mobility than electrons in metals. Additionally, water has a smaller secondary electron emission coefficient and is easier to deform and evaporate than most metals