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Review

A comprehensive review of electrocoagulation for water treatment: Potentials and challenges

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ABSTRACT

Electrocoagulation is an effective electrochemical approach for the treatment of different types of contaminated water and has received considerable attention in recent years due its high efficiency in dealing with numerous stubborn pollutants. It has been successful in dealing with organic and inorganic contaminants with negligible or almost no generation of by-product wastes. During the past decade, vast amount of research has been devoted to utilizing electrocoagulation for the treatment of several types of wastewater, ranging from polluted groundwater to highly contaminated refinery wastewater. This paper offers a comprehensive review of recent literature that has been dedicated to utilizing electrocoagulation for water treatment, focusing on current successes on specific applications in water and wastewater treatment, as well as potentials for future applications. The paper examines such aspects as theory, potential applications, current challenges, recent developments as well as economical concerns associated with the technology. Most of the recent EC research has been focusing on pollutant-specific evaluation without paying attention to cell design, process modeling or industrial applications. This review attempts to highlight the main achievements in the area and outlines the major shortcomings with recommendations for promising research options that can enhance the technology and broaden its range of applications.

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1. Introduction

Water scarcity is one of the greatest current and future challenges that face humankind as the world's population and water consumption rates continue to grow. This has led to a renewed interest in developing cost effective, reliable and environmentally friendly wastewater treatment technologies that would be able to reuse the huge amounts of wastewater generated from various industries. Although several wastewater treatment technologies are available and have been applied for a long period, most of these water treatment technologies consume huge amount of energy from carbon-based energy sources, which are non-renewable and contribute to carbon dioxide emissions.

Wastewater treatment technologies could be categorized into three major groups: Physical, chemical or biological processes; examples of unit operations from each category are illustrated in Fig. 1. A typical wastewater treatment plant consists of a combination of physical, chemical and biological unit operations to target the removal of different constituents/pollutants. Physical unit operations depend purely on the physical separation of pollutants from wastewater without causing a significant change in the chemical or biological characteristics of the treated water.

Chemical processes are referred to as additive processes, as they require the addition of chemicals to react with the desired contaminants and remove it. The additive nature of chemical processes makes them less attractive compared to other processes as they increase the net dissolved constituents in wastewater and render it impractical to reuse in other applications. Biological unit processes utilize microorganisms for the biodegradation of contaminants in wastewater, and the main aim of these processes is to reduce the organic content and nutrients in wastewater. Biological units are generally classified into aerobic, anaerobic or facultative depending on the availability of dissolved oxygen in wastewater (Asia, 2003).

Other than the above-mentioned processes, promising, relatively new technologies that utilize the concepts of electrochemistry are also available such as electrocoagulation (EC), electrooxidation and electrofloatation. Although using electricity for water treatment applications goes back to the 19th century, when EC was used for the treatment of drinking water in the United States, they were found impractical due to the high capital and electricity cost required (Chen, 2004). During the past two decades, electrochemical wastewater treatment technologies started to regain importance as an environmentally friendly option that generates minimal sludge, requires no chemical additives and minimal footprint without compromising the quality of the treated water. This paper focuses on reviewing recent advances in electrocoagulation with the aim of identifying the current state of the technology and its potential as an effective water treatment method. Despite the considerable number of publications about electrocoagulation, they tend to focus on laboratory scale experiments that prove the effectiveness of the technology in the removal of specific pollutants. Few authors looked into the kinetics, modeling, cell design, cost analysis, integrating electrocoagulation with existing technologies, scale-up and industrial applications, which are key factors that represent major challenges to the success of electrocoagulation. This review attempts to point out specific gaps, where more research is needed to develop electrocoagulation as a reliable and cost effective water treatment technology.

Electrocoagulation (EC) is an emerging technology in water and wastewater treatment, as it combines the benefits of coagulation, flotation and electrochemistry. The theory behind coagulation/flocculation and (EC) is basically the same. Both methods target the removal of particles from wastewater through destabilizing/neutralizing the repulsive forces that keep the particles suspended in water. When the repulsive forces are neutralized, the suspended particles will form larger particles that can settle down for easier separation from water. The main advantage of EC over chemical coagulation/flocculation CC/CF is that coagulation/flocculation uses chemical coagulants/flocculants such as metal salts or polyelectrolytes while in EC the coagulants are generated in situ by the electrolytic oxidation of an appropriate anode material which results in much less sludge generation. Another major advantage of EC over CC/CF and other conventional water treatment methods is the potential of treating oily water, where the presence of electric current can contribute to the electrocoalescence of oil droplets. Electrocoalescence has been proven effective in dealing with tight emulsions, where the droplets are very small (Mhatre et al., 2015). Very tight emulsions are often encountered in the Oil and Gas industry, either through the presence of fine water droplets in oil or vice versa, as is the case in produced water. The detailed theory of

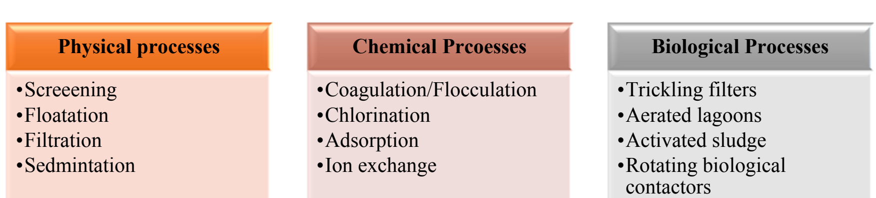

Fig. 1. Classification of typical unit operations in wastewater treatment plants.