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Industrial park wastewater deeply treated and reused by a novel electrochemical oxidation reactor

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HIGHLIGHTS

- A novel electrooxidation reactor for effluent treatment from industrial park sewage plant was described in this paper.
- The electro-oxidation technique could decompose residual pollutants in effluent completely and efficiently.
- The treated effluent met the reuse water standards with a lower operating energy consumption.
- This electrooxidation technique was beneficial for wastewater reuse.

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ABSTRACT

Effluent from industrial park sewage treatment plants contains residual contaminants that are mostly composed of non-degradable substances, which results in pollution of local aquatic systems. In this study, a novel electro-oxidation reactor for industrial park wastewater treatment was developed and described. The developed reactor was based on plug flow through meshed plate electrodes composed of titanium (Ti) as cathodes and Ti/PbO_2 as anodes. The system could decompose residual pollutants completely and efficiently. Under the optimal operating conditions of neutral pH, a flow cross-velocity of 0.75 m h^{-1}, a current density of 5.0 mA cm^{-2}, and a surface-to-volume ratio of 0.25 m^2 m^{-3}, the chemical oxygen demand (COD) and color of wastewater from an industrial park sewage treatment plant decreased to below 60.0 mg L^{-1} and 20 Hazen, respectively, after 30 min of electrolysis. Additionally, the microbial content decreased from 7×10^4 CFU mL^{-1} to 0 CFU mL^{-1} during electro-oxidation, the COD current efficiency was 16.55%, and the energy consumption for 1 ton of effluent was 4.12 kWh. The operating cost for effluent was $0.57 per ton according to the local electricity price of $0.14 kWh^{-1} for industries. The effluent quality after deep treatment met the needs of recycling water quality and could be reused for miscellaneous water consumption and scenic purposes, resulting in reduced use of water resources and pollution.

1. Introduction

1.1. Industrial park wastewater

The zoned developmental pattern of modern industries has led to centralized treatment of wastewater generated during industrial production that is pooled from various factories built in the industrial park prior to its discharge into the environment. These types of wastewater treatment systems feature a large flow and complex composition. In 2012, the total amount of industrial wastewater discharged was 22.16 billion tons, about 80% of which was treated by centralized wastewater plants according to the 2012 Report on the State of the Environment (SOE) in China. The pollutants were primarily composed of non-degradable substances [1,2]; thus removal of these non-degradable pollutants has become a crucial social issue.

Traditional technologies including physical, chemical, and biological processes can efficiently degrade most pollutants (excluding biorefractory compounds), improving wastewater quality before its discharge into the environment [3,4]. However, there are still considerable amounts of residual pollutants in the effluent from centralized sewage treatment plants in industrial parks following treatment [5]. Indeed, the total amount of chemical oxygen demand (COD) discharged via industrial wastewater was 3.38 million tons in 2012 according to the 2012 SOE. Additionally, the absolute amount of pollutants discharged into the environment from these waste streams was large, even though the concentration of

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pollutants in the effluent was low and met local emission standards. Accordingly, it is necessary to remove as much of these residual pollutants as possible to enable reuse of the effluent for miscellaneous water consumption and scenic purposes. Several advanced treatment systems have been developed to accomplish this in recent years [6], including those employing Fenton reagent, photo-Fenton, and ozonation processes.

1.2. Electro-oxidation treatment

Electrochemical technology (EC technology) is an environmentally friendly method that has been widely studied for its applicability to wastewater treatment [7,8]. Electro-oxidation (also known as anodic oxidation), is a type of EC technology that has recently received increased attention because it does not involve the use of extra chemicals throughout the procedure [9]. Various electro-oxidation processes for wastewater have been reported to remove more persistent and non-degradable pollutants than traditional physicochemical methods, and many studies have focused on the electrodes and the processing parameters used for the treatment of various types of wastewater by electro-oxidation [10–12]. Most of these studies have achieved mineralization of organic compounds, confirming that electro-oxidation processes could be used to treat wastewater containing biorefractory compounds.

In general, electro-oxidation can be used for two purposes, pretreatment to improve the biodegradability of wastewater and deep treatment of effluent from sewage plants. The latter is more important for application of wastewater as a means of resource and environmental protection. To accomplish this, it is necessary to develop new methods for electro-oxidation that improve current efficiency and reduce operating costs to meet the needs of deep wastewater treatment and recycling.

1.3. Novel electro-oxidation reactor

Existing electrochemical devices consist of continuous reactors and sequencing batch reactors [13]. Mass transfer is a key factor that affects the efficiency of pollutant removal and electricity use. Mixing plants, mechanical stirring, and air bubbling are often used to enhance mass transfer of pollutants in aqueous solutions. However, some novel structures of electrochemical reactors such as three-dimensional fixed- and fluid-bed EC reactors have been developed to improve the efficiency of pollutant removal and electricity use [14,15].

A novel plunger flow electrochemical reactor that combines a plunger flow pattern and meshed plate electrodes has been developed to improve current efficiency during the electrolysis of pollutants in aqueous solutions [16]. Plunger flow (also known as tubular or plug flow) involves piston-like movement through meshed plate electrodes without any back mixing. In this method, each micro-volume fluid element receives the same reaction time, enabling achievement of a higher removal rate of pollutants in a continuous flow system. The meshed structure of electrodes provides enough channels for orthogonal flow of fluid through electrodes, as well as larger acting surfaces for pollutants electrolysis relative to other plunger flow electrochemical reactors [17]. Hydrodynamic analysis revealed that the meshed plate electrodes made a positive contribution to the uniform distribution of the liquid flow field, and that only 3.2% of the back-mixing area formed in the reaction region [18]. In this study, some key information regarding suitable electrodes, flow patterns, optimized current density and economic evaluation of deep wastewater treatment by the novel plunger flow electrochemical reactor are reported in detail. The results presented herein will facilitate further large-scale application of the novel electrochemical reactor in wastewater treatment.

2. Experiment

2.1. Plunger flow electrochemical reactor

The novel plunger flow electrochemical reactor (PFER) included the cell, inlet area, outlet area, electrodes, and a constant current DC power supply (Fig. 1). The cell consisted of a ditch-shaped piece of polyvinyl chloride with dimensions of $5.8 \times 5.8 \times 78.0$ cm and a total effective volume of 2400 mL. The electrodes, which were composed of alternately arranged anodes and cathodes, were positioned vertically along the flow direction in the ditch-shaped cell. The cathodes were mesh-structure titanium (Ti) plates of 5.5×5.5 cm, and the anodes were mesh-structure plates of Ti based on the coating electrode (Ti/PbO_2 electrode) with the same dimensions of the cathodes, while the distance between the anode and cathode was only 2.0 cm. The surface-to-volume ratio, defined as the ratio of the amount of surface area of anodes relative to the total effective volume of the ditch-shaped cell, was 0.25 $m^2\,m^{-3}$. Additionally, the inlet and outlet areas were designed to have a bell-mouthed shape according to the CFD (Computational Fluid Dynamics) results, which was beneficial for fluid distribution when flowing into and out of the reactor.

Test samples from the final sedimentation tank in the industrial park sewage treatment plant were pumped into the ditch-shaped cell through the inlet area, after which they flowed orthogonally through the electrodes, and finally through the outlet area. The pollutants remaining in the effluent were further decomposed by the action of the electric field on the electrodes.

2.2. Material

The physicochemical characteristics of wastewater used in this study (COD, color, pH, and coliforms) were analyzed according to

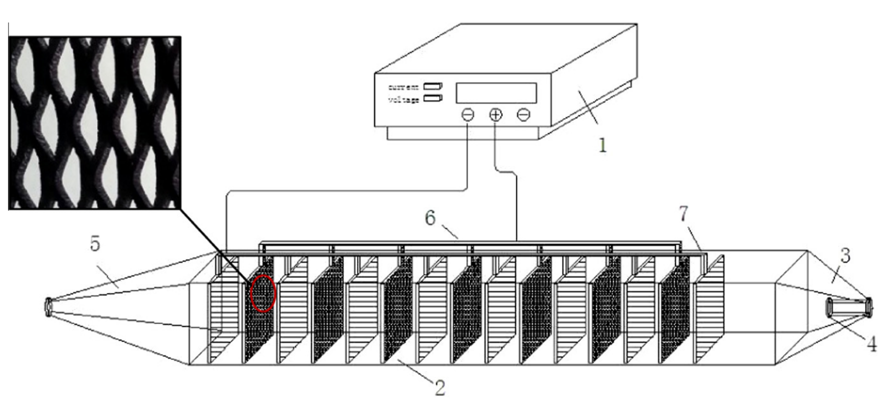

Fig. 1. Experimental device (1) DC power supply, (2) electrolysis cell, (3) inlet, (4) blocking flow plate (5) outlet, (6) anode (Ti/PbO_2), (7) cathode (mesh-structure titanium).