Application of Electro-Fenton Oxidation Technology in Industrial Wastewater

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Abstract. The treatment of industrial wastewater is one of the key research topics. Researchers found that traditional wastewater treatment technology has some shortcomings in many aspects. Therefore, exploring new and efficient water treatment technology is particularly important. This paper focuses on the electro-Fenton (EF) oxidation technology, which uses the electrochemical reaction to generate strong oxidants that can effectively degrade the organic pollutants in wastewater, and have good treatment effect and high energy efficiency. By consulting the data, this paper analyzes the application of EF Oxidation Technology in industrial wastewater. The research shows that the EF oxidation technology can effectively remove harmful substances in industrial wastewater, providing a new solution for treating industrial wastewater. However, the technology still faces challenges such as high energy consumption and limited processing efficiency. Future research should focus on solving the energy efficiency problem, and further enhance the application potential of EF technology in industrial wastewater treatment by optimizing technical parameters and equipment design.

Keywords: Industrial wastewater; Electro Fenton oxidation technology; wastewater treatment.

1. Introduction

With the acceleration of industrialization, the amount of industrial wastewater is increasing, followed by the increasingly serious problem of environmental pollution. The traditional wastewater treatment technology is often ineffective in the treatment of high-concentration, toxic, and harmful substances, and cannot meet the increasingly stringent discharge standards. Fenton technology, as a new water treatment method, has attracted more and more attention due to its efficient oxidation ability and wide applicability.

The traditional Fenton technology has many disadvantages such as high dosages of H2O2 and fe2+ and more iron sludge [1]. Given this, some scholars have combined Fenton technology with electrochemical technology to continuously regenerate Fe2+ at the cathode, so there is a more perfect electric Fenton technology. As a new type of water treatment process, electro-Fenton (EF) technology has been proven to be able to effectively degrade pollutants in industrial wastewater. Its main feature is that it can generate hydrogen peroxide (H2O2) in situ, and then produce hydroxyl radical · Oh, which is second only to fluorine, to degrade pollutants into water and carbon dioxide [2].

Although the electro-Fenton (EF) technology has made great breakthroughs compared with the traditional wastewater treatment process, there are still some technical challenges and shortcomings in the practical application, which need further research and improvement. In this paper, the principle of EF technology and its application in the treatment of various industrial wastewater are discussed in detail. At the same time, it also analyzes the shortcomings of this technology and the challenges in the future. By analyzing the actual effect of this technology in different industrial fields, this paper aims to promote its application in a wider range of industrial fields.

2. Overview of EF Oxidation Technology

2.1. Classification of EF Oxidation Technology

EF is an advanced oxidation technology, which is suitable for the treatment of organic wastewater with high salinity, high color, high toxicity, and difficult biodegradation. Different from the traditional Fenton oxidation technology, relevant researchers have proposed the EF oxidation system which combines Fenton oxidation technology and electrochemical oxidation technology. It is one of the most widely used technologies in water treatment at present.

According to the source of the E-Fenton reagent, it can be divided into the following four categories, as shown in Figure 1 [3].

(1) E-Fenton/H2O2 method (hydrogen peroxide method): Fe (II) is added externally, and H2O2 is formed in situ at the cathode;

(2) E-Fenton/Fe ox method (iron oxide method): Fe (II) is generated through an iron sacrificial anode, and H2O2 is added from the outside;

(3) E-Fenton/Fe re method (iron rhenium alloy method): by adding Fe (III) and H2O2 externally, Fe (II) is generated by Fe (III) cathode reduction;

(4) E-Fenton/H2O2/Fe re method (hydrogen peroxide/iron rhenium alloy method): Fe (II) is formed by the reduction of externally added Fe (III) at the cathode, while O2 on the cathode surface is electrocatalytic to generate H2O2 in situ.

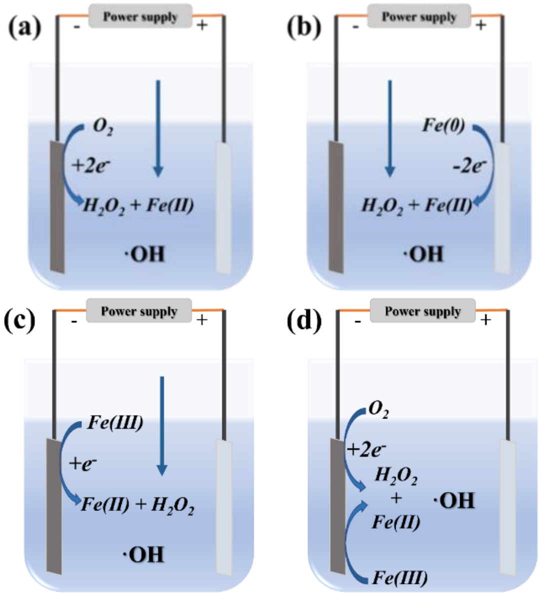

Fig 1. Schematic diagram of various EF reaction mechanisms:
(a) E-Fenton/H2O2; (b) E-Fenton/Fe-ox; (c) E-Fenton/Fe-re; (d) E-Fenton/H2O2/Fe-re [3].

2.2. Reaction Principle of EF Oxidation Technology

The reaction process of EF degradation of pollutants can be divided into three steps: 1. In the electrolytic cell, oxygen molecules are adsorbed on the cathode surface, and H2O2 is generated through two-electron oxygen reduction reaction (ORR) [formula (1)]; 2. The generated H_2O_2 subsequently undergoes catalytic activation by external metal ions, primarily Fe^{2+}, resulting in the formation of hydroxyl radicals (·OH) as indicated in Equation (2); 3. These highly reactive ·OH radicals non-selectively attack the organic pollutant molecules, leading to their degradation into inorganic by-products.

$$O_2 + 2H^+ + 2e^- \rightarrow H_2O_2 \quad E^{\circ} = -0.695V(vs.SHE) \tag{1}$$

$$Fe^{2+} + H^+ + H_2O_2 \rightarrow Fe^{3+} + H_2O_2 + \cdot OH \tag{2}$$

2.3. Advantage Analysis

EF oxidation is an advanced oxidation process developed in recent years. It uses on-site electrochemical technology to oxidize organic substances in water. It has the advantages of simple equipment, easy to realize automatic control, small floor area, and short treatment cycle, no need for chemical agents, and easy to be combined with other treatment processes. As shown in Table 1.

Table 1. Advantage analysis of electric Fenton Technology.

Comparison project	Electro-Fenton technology	wastewater treatment
Oxidation ability	It can produce strong oxidative hydroxyl radicals and degrade organic pollutants without selectivity	The production of strong oxidative hydroxyl is relatively weak, and the removal effect of refractory organics is limited
Dosage of medicament	In situ generated reagent, less usage	A large amount of reagent is required
Sludge production	Less, only 1/5 to 1/10 of the traditional Fenton Method	Too many, high subsequent processing costs
Reaction conditions	Normal temperature and pressure, easy-to-control current, voltage, and other parameters	May require harsh conditions such as high temperatures and high pressure
Applicability	Wide range, suitable for a variety of difficult-to-treat industrial wastewater	There are certain limitations
Compatibility	Can be used in combination with other technologies	Relatively poor compatibility
Floor area	Small, compact equipment structure	Larger

3. Treatment of Industrial Wastewater by EF Oxidation Technology

3.1. Electroplating Industry

The electroplating industry is one of the important fields of industrial wastewater, which often contains heavy metal ions and organic solvents. A large amount of wastewater will be produced in the cleaning process of plating parts in the electroplating process. Due to the different plating species, bath composition, process, and other conditions, the pollutants in the electroplating wastewater are relatively complex. The main components are various heavy metal salts, such as copper (Cu), zinc (Zn), nickel (Ni), chromium (CR), etc., and complexing agents (such as EDTA, tartrate, triethanolamine, etc.) added to improve the coating structure, making the heavy metal ions in the wastewater exist in the form of complex state. The application of EF oxidation technology can effectively remove the complex heavy metals and organic pollutants in wastewater.

Wu Yang studied this process for heavy metal ions in electroplating wastewater through experiments [4]. The research results show that under the operating conditions of residence time of 0.5~1 h, hydrogen peroxide dosage of 3.4~8.5 mlgl · h, and current density of 20~30 MA/cm2, the process has a good removal effect of copper and nickel in wastewater, and can achieve standard discharge [4].

3.2. Printing and Dyeing Industry

In the process of printing and dyeing, to improve the color fastness of textiles and the style of finished products, mordants containing heavy metals, fuel oxidizer catalysts, and other agents will be widely used. However, the chroma value of the treated wastewater was significantly reduced and reached the discharge standard when the EF oxidation technology was introduced into the wastewater treatment. Liu Wei and others used the EF Method of electrolytic cells to explore the factors affecting the removal rate of printing and dyeing wastewater [5]. The experimental results show that when the electrolytic voltage is 8 V, the electrolytic current density is 40 Ma · cm-2, and the concentration of FeSO4 is 15 mmol · L-1, the treatment effect of printing and dyeing wastewater is the best [5]. Shi Shen et al. used the self-made electric Fenton reactor to study the treatment of printing and dyeing wastewater, and found that pH, aeration rate, reaction time, and other factors can affect the treatment effect [6]. Under the conditions of pH=3, aeration rate of 0.1 m3 · H-1, and reaction time of 40 min, the removal rate of chemical oxygen demand (COD) can reach 73.5%, and the treatment effect is good [6].

3.3. Landfill Leachate

A large amount of landfill leachate will be produced in the process of stacking and landfilling the waste generated in industrial production. Leachate may contain a large amount of organic matter, usually containing a large number of organic pollutants, ammonia nitrogen, heavy metals, and other toxic substances that are difficult to degrade. Wang et al. Studied the treatment of leachate nanofiltration concentrate by EF process, and found that the maximum COD removal rate reached 80.7% when the reaction time was 2h, the current density was 6.471 MA/cm2, n (H2O2): n (Fe2+) was 12, and the pH was 3.78 [7]. Zhang, et al. Used the intermittent recycling method of the EF process to treat landfill leachate. The experiment found that the EF method can effectively remove COD in landfill leachate [8]. Mohajeri et al. Also studied was the treatment of semi-aerobic landfill leachate by EF oxidation method using aluminum electrode [9]. The results showed that the EF oxidation method was a very effective method for the treatment of landfill leachate, but it was required that hydrogen peroxide and Fe2+ should not be excessive. Under the optimal conditions, the highest COD removal rate and decolorization rate were 92% and 93%, respectively [9].

4. Challenges and Development Prospects of EF Oxidation Technology

Although the EF oxidation technology has many advantages in industrial wastewater treatment, it also faces some challenges in practical application, mainly including energy consumption, cost, and limited treatment efficiency.

4.1. Energy Consumption

Because this technology requires the electrolysis process to produce hydroxyl radicals, this process often needs high-power support. In the treatment of high-concentration wastewater, the problem of energy consumption is more obvious, which may lead to a significant increase in the treatment cost. Therefore, how to reduce the energy consumption in the electrolysis process and improve energy efficiency is an important issue faced by the EF oxidation technology. In the future, a variety of solutions can be explored to reduce the energy consumption of EF oxidation technology. For example, Zhang and others proposed that in the future, we could develop an EF Method to realize complex breaking and collaborative recovery of heavy metal pollutants in wastewater, and design and build a neural network model to realize active control and optimization of the electrochemical process [3] In this way, the high-value utilization of heavy metal wastewater treatment and resource recovery can be realized with the characteristics of high efficiency, low energy consumption and no secondary pollution. The results show that the working pH of the na6tpp EF system is widened to 3-7, which effectively avoids the production of iron sludge, and the breaking efficiency is 99.7%. At the same time, compared with the commercial Zn symmetrical battery, the zinc electrode is based on in-situ preparation (CP@Zn). It has better corrosion resistance, hydrogen evolution inhibition, and higher electron transfer rate.

4.2. Limited Processing Efficiency

The treatment efficiency of EF oxidation technology is limited by many factors, including the pH value, temperature, and iron ion concentration of the reaction environment. For example, under the conditions of 1a (current density of 10ma/cm2) and 0.6mmol/l fe2+, Mao Chaolin studied the removal effect of COD in wastewater by treatment time [10]. The results show that the removal rate of COD increases with the increase of treatment time, and the rate increases rapidly in the initial 2h and tends to be stable in the later stage. This shows that EF oxidation can only rapidly decompose the characteristic pollutants that are easy to decompose in wastewater but cannot decompose most of the pollutants that are difficult to degrade.

In addition, the low solubility and slow diffusion of oxygen in water will also limit the treatment efficiency of EF technology. To solve this problem, a scientific research team from Tongji University proposed the local oxygen enrichment (LOC) strategy, constructed a cathode with an oxygen enrichment effect and revealed the local oxygen enrichment mechanism by combining in-situ electrochemical characterization technology and theoretical calculation method, as shown in Figure 2 [11]. Unlike the simple oxygen diffusion (SOD) process near the traditional electrode, the electrode can continuously extract dissolved oxygen from the bulk solution to the electrochemical reaction interface, thereby reducing or even eliminating the aeration demand. The oxygen utilization rate has increased by more than 11 times, and the energy consumption of the EF process has decreased by more than 65%.

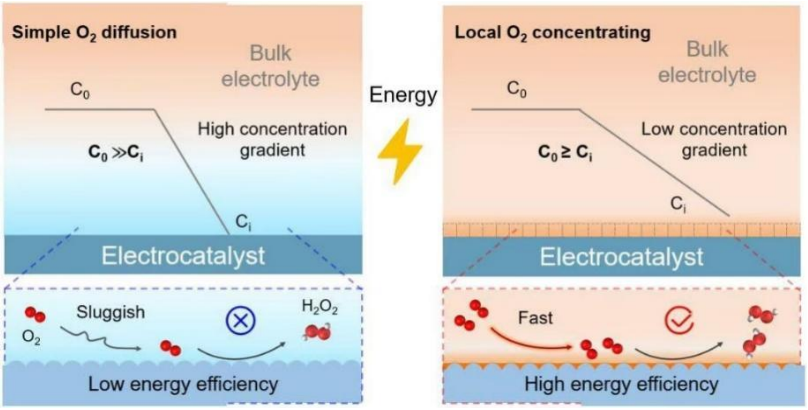

Fig 2. Comparison between local oxygen enrichment (LOC) strategy and the traditional "simple oxygen diffusion (SOD)" process [11].

5. Conclusion

As an advanced water treatment technology, EF oxidation technology has shown great application potential in the field of industrial wastewater treatment by its high-efficiency removal ability of organic pollutants, controllable electrochemical process, and less use of chemical reagents. EF technology EF oxidation technology generates reactive oxygen species, especially hydroxyl radicals, through electrochemical reactions, which can rapidly degrade organic pollutants that are difficult to treat in water. This method has the advantages of simple equipment and easy-to-realize automatic control. This paper points out that this technology combined with EF oxidation technology can effectively remove all kinds of pollutants in electroplating wastewater, printing and dyeing wastewater, and landfill leachate, and shows the remarkable effect of this technology in the actual industrial wastewater treatment.

However, this method still has problems such as energy consumption and cost, limited processing efficiency, and so on. Through continuous research and technological innovation, EF oxidation technology is expected to overcome these challenges, further improve its application effect in wastewater treatment, and make greater contributions to environmental protection.

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