Progress in Petrochemical Wastewater Treatment

Yanji Li [1], Yiming Zhang [2] and Mingyu Zong [3, *]

[1] International Education Institute and Environmental Engineering, Jiangsu University of Technology, Jiangsu, China

[2] Oil & Gas Storage and Transportation Engineering, Southwest Petroleum University, Sichuan, China

[3] Water Supply and Drainage Science and Engineering, Changzhou University Huaide College, Jiangsu, China

* Corresponding Author Email: zongmingyu@ldy.edu.rs

Abstract. Untreated or poorly treated petrochemical effluent can damage plants and animals in natural water bodies. It is a major industrial contaminant that creates several harmful chemicals. As a result, creating a straightforward, effective wastewater treatment technique is crucial. At this stage, countries around the world attach great importance to environmental protection and constantly improve the requirements for wastewater treatment, especially petrochemical wastewater. To meet the water treatment standards, the relevant personnel have continuously strengthened the research of wastewater treatment technology, and have achieved good results. This paper introduces the types and discharge characteristics of pollutants in petrochemical wastewater and summarizes the research progress of petrochemical wastewater treatment technology. In this paper, three wastewater treatment technologies, namely electromagnetic method, BAF, and suspension packing bioreactor, are analyzed, and the problems and challenges of the current wastewater treatment technology are proposed.

Keywords: Petrochemical industry; wastewater treatment technology; wastewater.

1. Introduction

The petrochemical industry has always been an important area of global energy and chemical production. However, its huge production volume has also led to the generation of a large amount of wastewater, which has caused serious harm to the marine environment, human health, etc.

Because the petrochemical industry uses complicated raw materials, complicated processes, and complicated side reactions, its effluent typically contains a lot of harmful compounds that can be classified as either organic or inorganic contaminants. The study and application of petrochemical wastewater treatment technology have grown in significance in recent years due to the increased awareness of environmental protection and the stricter environmental restrictions. Wastewater from the petrochemical industry has been treated using a variety of conventional techniques, including electrocoagulation, adsorption, dissolved air flotation, and electrochemical oxidation. However, these techniques have some disadvantages, such as high energy consumption, low recovery rates, large sludge generation, and high operating costs [1]. To get over these restrictions and difficulties, new, creative, and hybrid wastewater treatment techniques are therefore required.

To support the sustainable growth of the petrochemical industry, encourage the adoption of green production principles, and positively impact the preservation of human and environmental health, this paper delves deeply into the technology of petrochemical wastewater treatment.

2. Overview of Petrochemical Wastewater

2.1. Types of Contaminants in Petrochemical Wastewater

Petrochemical wastewater refers to the wastewater released during the petrochemical industry's production process. As Table 1 illustrates, this wastewater contains a wide range of contaminants, primarily heavy metals, organic pollutants, inorganic salts, and oil compounds. Because of their biological toxicity and persistence, heavy metals (including lead, cadmium, and mercury) are difficult for the environment to break down naturally. They also easily accumulate in living things and can seriously damage ecosystems and human health through the food chain. Organic pollutants such as benzene, toluene, and polycyclic aromatic hydrocarbons have toxic effects such as carcinogenic, teratogenic, and mutagenic. Inorganic salt pollutants include sulfates, chlorides, etc., which can change the ionic balance of water bodies and affect the living environment of aquatic organisms. Oils tend to form an oil film on the surface of the water, hindering oxygen exchange, resulting in hypoxia in the water body.

The existence of a variety of wastewater components makes petrochemical wastewater treatment complex and diverse, and it is necessary to comprehensively consider the characteristics and treatment methods of different components to effectively purify wastewater and achieve the goals of environmental protection and resource recovery.

Table 1. Different types of petrochemical wastewater and the characteristic pollutants they contain [2].

Wastewater types	Particular pollutants
Refinery wastewater	Sulfur compounds, benzene, toluene, pyrene, anthracene, phenols, ammonia, and cyanide
Phenolic wastewater	Phenol, benzene, toluene, pstyrene
Coking wastewater	Cyanide, phenols, thiocyanates, ammonia, naphthalene, pyridine, quinoline, indices, and carbazole
Phenylamine wastewater	Aniline, catechol, and ammonia nitrogen
High-salt petrochemical wastewater	Inorganic salt, organic matter
High-alkaline synthetic wastewater	Acetate, acetic acid, cysteine sulfides, sodium bicarbonate, and ammonium chloride

2.2. Discharge Characteristics of Petrochemical Wastewater

The discharge of petrochemical wastewater has the remarkable characteristics of large quantity, complex composition, and strong toxicity. First, the amount of wastewater discharged in the production process of the petrochemical industry is huge, and the annual wastewater discharge can reach hundreds of millions of tons. Second, the composition of petrochemical wastewater is complex, and the wastewater produced has a variety of components, including toxic and harmful substances such as heavy metals and organic pollutants, as well as pollutants such as suspended solids, oils, acids, and alkalis. Third, many contaminants found in petrochemical effluent are very biotoxic, persistent, and bio accumulative, and once they enter the environment, they will seriously endanger human health and ecosystems.

3. Petrochemical Wastewater Treatment Technology

3.1. Electromagnetic Method

With the frequent occurrence of high-risk water pollution incidents such as marine oil spills and chemical oil leaks, serious environmental and ecological problems have been caused to the oceans and rivers. Since 1963, about 28 million barrels of oil have been leaked due to accidents [3]. To deal with such events, electromagnetic separation technology comes to the fore. Electromagnetic separation has also successfully replaced traditional physical adsorption technology and become one of the mainstream technologies to solve such incidents due to its wide processing range, remarkable separation effect, and low cost. The process flow of CoMag magnetic condensation is shown in Figure 1. The electromagnetic method is a technology that uses magneto hydrodynamics (MHD) based on the difference in conductivity between the aqueous phase and the organic phase, and uses magnetic powder to separate oil and water under the action of electromagnetic force. Magnetic powder has an excellent demulsification effect. At the same time, fine-grained magnetic powder (diameter r < 4μm) can also cause magnetic flocculation with oil droplets. The dissolved and emulsified oil in oily wastewater can be eliminated by the combined action of magnetic particles and an external magnetic field. And it is possible to efficiently gather and segregate dispersed oil [4]. Electromagnetic separation technology has been mature for a long time. The MHD offshore oil recovery system was established in 2003 through a collaboration between Harbin Futai Industrial Co., Ltd. and the Chinese Academy of Sciences' Institute of Electrical Engineering. By 2011, electromagnetic technology was used for oil-water separation in Daqing Oilfield. The frequency pulse oil-water coalescence technology was used for the first time in the oil-water separation process in Daqing Oilfield, which increased the oil removal efficiency by 30%. Jiang et al. used the electromagnetic field to elaborate on the flow and separation characteristics of the oil and water phases in the oil-water separation device. Numerical simulation shows that the oil-water separation effect reduces as water inlet flow increases and increases with magnetic field intensity, current density, oil droplet size [5]. Shengli Oilfield, China's second largest oil producing area, also began to carry out air-floatation magnetic separation wastewater treatment (OPS+CoMag) and on-site process tests in 2015. Compared with traditional treatment methods, it not only changed the current dependence on chemical agents, but also reduced costs and improved efficiency.

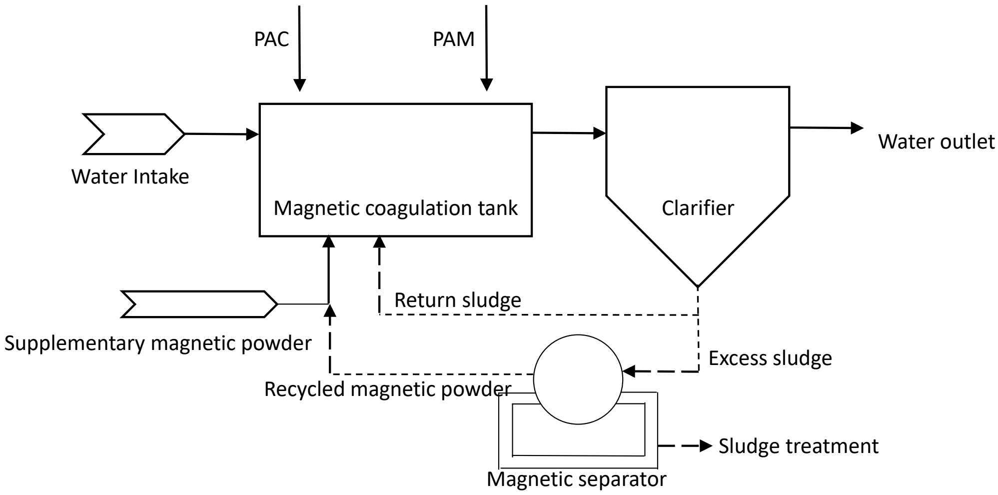

Fig 1. CoMag magnetic coagulation process flow [6].

3.2. Biological Aerated Filter (BAF) Combined Process

Higher standards for the treatment of oily wastewater have been proposed in recent years due to the acceleration of industrial expansion and the heightened level of environmental protection. However, it is challenging for any oil removal method to satisfy the demands of the present. The characteristics and makeup of oily wastewater, emission regulations, carrying capacity for the environment, and financial needs must all be combined. Through the combination of a variety of suitable treatment technologies, the synergistic effect of different technologies can be brought into play to make up for the shortcomings of individual processes to achieve good treatment effects.

BAF combined process BAF is a mainstream oil removal process that integrates filtration and biological oxidation. It can effectively remove SS, COD, nitrogen, phosphorus, and other harmful substances. It is suitable for deep treatment of oily wastewater. It is generally used as the terminal treatment technology of the combined process to solve the residual dissolved oil and emulsified oil with smaller particle sizes. Compared with the ordinary activated sludge method, BAF not only has a high oxygen transfer rate and high organic load but also has a small footprint and no sludge expansion. However, the process has very strict requirements on the SS of the influent. Generally, the SS is required to be less than 100 mg/L, and the optimal operating conditions are below 60mg/L. Therefore, it is necessary to pre-treat the BAF influent [7]. Given this, BAF needs to be combined with other processes to achieve better oil removal effects. The processes combined with BAF include the early UBF-BAF combination process and the Fenton reagent-BAF combination process. The early combination process mainly solved the shortcomings of BAF technology by removing suspended matter in the incoming water through filtration and then using BAF to remove most of the organic matter. In recent years, the BAF combination processes that have been upgraded on the existing basis include the ozone oxidation-BAF combination process and the ozone oxidation-BAF and Fenton-BAF combination process. After condition optimization, they can meet the national first-level emission standards. The ozone oxidation-BAF combination process is simpler to operate than the Fenton-BAF process, and no sludge is produced, eliminating the trouble of sludge treatment, at the same time has a higher deep removal rate [8]. The ozone oxidation-BAF combined process has been studied in depth in recent years. By adding metal ions as catalysts and utilizing the combined effects of indirect oxidation by free radicals and direct oxidation by ozone molecules, the oxidation efficiency is improved while reducing the treatment cost. With the increasing complexity of industrial oily wastewater, higher requirements are placed on the treatment process. In addition to oil removal, total suspended solids, total nitrogen, ammonia, heavy metals, etc. are also required to be removed. The combined process is not only required to meet emission standards, but also to be reasonable, efficient, simple to operate, and low-cost [9]. Based on the above background, the designed combined process is more complex and efficient than the earlier combined process. Liu et al. designed an integrated combined process treatment technology of UASB, SBR, and EO-BAF for the highly concentrated and complex toxic wastewater of tannery wastewater [10]. The primary functions of the UASB process in this combined system are to eliminate readily degradable organic materials and increase wastewater's biodegradability. The SBR process is crucial in the removal of nitrogen and phosphorus and thoroughly eliminates any remaining organic debris. In the final BAF process, the EO process completes post-polishing treatment and increases the biodegradability of SBR effluent. After mixed treatment, all of the markers in the tanning wastewater had removal rates above 90%, suggesting that deep treatment of high-intensity tanning wastewater has considerable potential.

3.3. Suspended Media Bioreactor

As an efficient, low-consumption, easy-to-maintain, and easy-to-operate water treatment solution, suspended packing bioreactors are gradually being widely used in the field of petrochemical wastewater treatment. Compared with the traditional activated sludge method, FBBR technology shows higher pollutant removal efficiency and wider applicability, especially for the treatment of refractory organic compounds. According to the experimental results, it can be clearly seen that this reactor not only has good oxygenation capacity, but also has strong load impact resistance. When the filler addition rate is 50%, the ordinary aeration tank can increase the oxygenation capacity by more than 2 times. It can not only ensure the removal and consumption of pollutants, but also maintain the stability of water quality. When the filler addition rate is 50% and the HRT is 8h, the COD removal rate is 75.0%. The ammonia nitrogen removal rate is 85.2%, the turbidity removal rate is 85.7%, and the SS removal rate is 86.2%, which has a good removal effect [11].

4. Issues and Challenges

The complexity of hazardous substances in petrochemical wastewater is growing along with the technology used to treat it, and issues and difficulties with the electromagnetic technique, BAF, and suspended filler bioreactor are continually brought to light.

Although the electromagnetic method has a strong treatment effect, it has high energy consumption, complex equipment requirements, and limited adaptability to wastewater components. At the same time, oxidation by-products may be generated during the treatment process, increasing the risk of secondary pollution. However, its advantages of less head loss, no need to lift sewage, and a small footprint are very prominent [6]. For the BAF method, the treatment effect of high-concentration wastewater or complex wastewater is not good, and the plugging of the filler during operation will also affect the stability of the system operation. At the same time, for new technology-suspended filler bioreactors, there are problems such as filler shedding, uneven distribution, and high operating costs. In addition, the strong dependence on filler performance and the possibility of foam or odor generation increase the complexity of system management.

In the future, the electromagnetic method can reduce its operating costs by developing low-energy electromagnetic equipment and optimizing electromagnetic field distribution. At the same time, it can be combined with other advanced oxidation treatment technologies to form a collaborative treatment process to enhance the adaptability of this method to high salt and high toxicity. The BAF method can focus on the innovation of fillers and the intelligence of the system, the development of anti-clogging and self-cleaning fillers can significantly improve the stability and life of the filter. New technology suspended filler bioreactors, can be combined with technologies such as membrane bioreactors to broaden its application scenarios.

The development of these three methods will move towards more energy saving, lower cost, and higher efficiency to meet the increasingly complex requirements of petrochemical wastewater treatment.

5. Conclusion

The research on petrochemical wastewater treatment technology has achieved good results. The research and development of a variety of new technologies has provided a strong technical guarantee for the practice of petrochemical wastewater treatment. However, from the actual perspective of wastewater treatment, there are still many problems. Although the current wastewater treatment can meet the standards, it cannot fundamentally solve the problem of environmental pollution. Based on this, we must continue to increase the research on wastewater treatment technology, promote the development of wastewater treatment technology in the direction of clean production, and increase the control of water pollution at the source and throughout the production process. The current application of wastewater treatment technology has the problem of high cost, which affects the application of wastewater treatment technology, and its economic efficiency needs to be further improved.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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