Development of Ceramic Membrane Combination Process in the Treatment of Industrial Wastewater in China

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Abstract: Due to the advantages of ceramic membrane such as high separation efficiency, easy operation, good chemical stability and low energy consumption, it has an expansive application prospect in the field of industrial wastewater treatment. However, the ceramic membrane has a low removal effect to the contaminants whose molecular diameters are smaller than the membrane pores, the poor water quality also aggravates the pollution and shortens the age of ceramic membrane. Therefore, it is significant to research the combination process of ceramic membrane. This article summarizes the current ceramic membrane combination process in industrial wastewater treatment, and describes their respective characteristics, mechanism of reaction and removal effects. Ultimately, we would put forward the direction of the ceramic membrane combination process in the future.

1. Introduction

In recent years, the emission of industrial wastewater in China was approximately 20 billion tons per year. If wastewater is improperly treated, the local ecological environment will be affected seriously. The current methods for industrial wastewater treatment mainly include chemical methods, physical methods, physical-chemical methods, and biological methods. Although the chemical treatment technique is relatively mature, the removal efficiency reduces significantly when the concentrations of pollutants are low. The biological method has a long running time, and it is unstable by the influence of seasonal change. Because of the characteristics such as good chemical stability, long operating cycle, anti-pollution, easy cleaning and regeneration, non-polar ceramic membranes is attracting increasing attention of related researchers. Initially, ceramic membrane had expensive price and small application range, but the cost of membrane production has been gradually declining with the continuous improvement of membrane technology, which is pushing the application of ceramic membranes [1].

In reality, if the ceramic membrane is used as one of the industrial wastewater treatment units, we should reach the requirements of influent water quality, otherwise the ceramic membrane will be easily contaminated and aged. The combination of ceramic membrane and other processing units is contributed to the complementary advantages among the units. Based on the research on ceramic membrane treatment of industrial wastewater in recent years, this article would focus on the characteristics, operating effects and related membrane fouling and aging of ceramic membrane combination process.
2. Ceramic membrane overview

2.1. The mechanism and classification of ceramic membrane
There are two mechanisms for the ceramic membranes to remove contaminants. The first is the self-retaining action of membranes, which can prevent particles larger than the membrane aperture from passing. So the ceramic membrane can separate and purify pollutants. The second is the adsorption capacity, which can adsorb small molecular weight contaminants though chemical bonds, van der Waals forces and electrostatic forces.

According to the pore size, ceramic membrane can be divided into microfiltration membrane, ultrafiltration membrane, nanofiltration membrane and reverse osmosis membrane. And the first three types of ceramic membranes are mainly applied in the industrial wastewater treatment [2].

According to the shape, which is determined by manufacturing technique and application field, ceramic membrane can be divided into single-channel tubular membrane, multi-channel tubular membrane, flat membrane and hollow fiber membrane. Among them, the hollow fiber membrane is widely used in the water treatment field, the tubular membrane has an abroad application in the solid-liquid separation processes such as high solid phase content and landfill leachate, and the flat membrane can be applied in the water resources field.[3].

2.2. Technical advantages of ceramic membranes
There are some inductions for the feature of ceramic membrane.

2.2.1. Good chemical stability. It is difficult for inorganic ceramic membrane to react with other substances and it has great resistance to oxidation and corrosion, so it can operate normally under the conditions of strong acid and strong alkali.

2.2.2. High mechanical strength. Ceramic membrane can withstand high strength scouring and ceramic fibers are hardly damaged during operation, thus the maintenance cost of ceramic membrane is low.

2.2.3. Long lasting. The ceramic membrane can be cleaned repeatedly, which greatly prolongs the service life of ceramic membrane and reduces the operating cost of the treatment process [4].

2.2.4. Good thermal stability. The thermal resistance of ceramic membrane is great. Most ceramic membranes can operate normally at the temperature below 800 ℃, some even reach 1000 ℃, so ceramic membrane can meet the temperature requirements of most industrial wastewater treatment [5].

2.2.5. Low energy consumption. Ceramic membrane can separate the contaminants at room temperature, requiring membrane pressure without additional medicines. Therefore the energy consumption of ceramic membrane is very low.

3. Application of Ceramic Membrane and Its Combined Process of Industrial Wastewater Treatment

3.1. Coagulation-ceramic membrane combination process
A lot of experiments showed that the quantity of pollution in water was reduced effectively and the removal efficiency of ceramic membrane was improved when coagulation process was used to be the pretreatment process[6]. After the combination process, the water quality of the effluent was relatively stable [7], and the turbidity of effluent decreased below the national drinking water standard [8].

The research of Yi Yanhong [10] showed when the combination of coagulation and ceramic membrane microfiltration process was as the pretreatment of pre-biochemical coking wastewater,
under optimal conditions the removal rates of turbidity, color degree, oil content, and CODcr were 95%, 80%, 90%, and 81%, respectively. This study indicated the high efficiency and great compatibility of coagulation-ceramic membrane combination process, and the process reduced the burden of the following treatment process.

3.2. Ozone Ceramic Membrane Ultrafiltration - Biological Activated Carbon Combination Process

The research showed that ceramic membrane was difficult to remove soluble organic matter and ammonia nitrogen [11], thus it hindered the wide application of ceramic membrane. Ozone can effectively reduce the molecular weight of pollutants in water and improve the biodegradability of wastewater, but not affect the normal operation of ceramic membrane [12]. At the same time, bioactive carbon (BAC) can also reduce the concentration of organic and ammonia nitrogen in water [13] by adsorption, so the combination of BAC, ozone and ceramic membrane can prolong the service life of the ceramic membrane and reduce the concentration of the pollutants in the water.

Guo Jianning [14] and others found that the removal rate of ammonia nitrogen could be improved by increasing the DO concentration of inflow water. And the appropriate DO concentration could reduce the ammonia nitrogen from 6.0 mg/L to 0.5 mg/L or less. By using ozone to degrade organic matter, UV254 removal can be enhanced, membrane flux can be increased by 25% to 30%, and processing performance can be improved.

3.3. The photocatalysis-ceramic membrane combination process

photocatalysis - Ceramic Membrane Reactor (PMR), which combines photocatalysis with ceramic membranes, develops rapidly in China. Due to the combination of two different processes, this combination process has multiple advantages and makes up for certain defects, which has a certain research value.

There are two different existing forms of photocatalyst, floating and fixed. The floating photocatalyst is put into the water for catalytic reaction and prevents from passing through ceramic membrane. The fixed photocatalyst is fixed on the ceramic membrane, and the photocatalytic reaction and membrane separation can simultaneously occur on the surface of ceramic membrane.

In fact, the PMR reactor has very strict requirements on the membrane, because the free radicals produced by the photocatalytic process may cause some damage to the membrane fibers and affect the normal operation of the membrane, but the stability of the ceramic membrane is sufficient to avoid strong oxidizing free radicals and solve the problem of difficult recovery of photocatalyst [15]. The contact area between the floating photocatalyst and the contaminants is larger than that between the fixed photocatalyst and the contaminants, so the reaction of the floating photocatalyst is more complete [16]. However, when the floating photocatalyst is trapped by the ceramic membrane, the ceramic membrane will have a certain degree of clogging, resulting in a decrease in the flux of the film, and therefore it is necessary to periodically backwash the ceramic film. Although the fixed photocatalyst does not have the problem of reduced membrane flux, it has a low catalytic efficiency [17,18], and the related issues need to be further studied and examined.

4. Conclusion

In summary, researchers pay more attention on ceramic membranes and their combination processes because of their high removal effect. Besides, when we treat different types of industrial wastewater such as petrochemical wastewater, printing and dyeing wastewater and electroplating wastewater, we should select the relevant combination process reasonably according to their unique water quality characteristic. In order to accelerate the large-scale application of ceramic membrane combination process, it is necessary to consider the following advice:

(1) At present, the ceramic membrane combination process has mainly existed in the laboratory test or trial operation stage, so it is necessary to assess the difference between the actual wastewater
treatment environment and the laboratory environment. Currently, we need a large number of operational parameters of membrane combination process in industrial wastewater treatment to evaluate its feasibility, and adjust the experimental conditions refer to the actual combination process operations.

(2) The ceramic membrane is more expensive than the organic membrane, so many experts have some research on reducing the costs of membrane manufacture in the conditions of guaranteeing membrane performance, such as finding cheap raw materials or additives, simple manufacturing processes, and so on.

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References
[1] C Zhao M, Zhou L and Cai Z 2016 Research progress of ceramic membrane and its combination process in drinking water treatment Water & Waste Eng. 52 133-40
[2] Geluwe S V, Braeken L and Bruggen B V D 2011 Ozone oxidation for the alleviation of membrane fouling by natural organic matter: A review Water Res. 45 3551-70
[3] Zhang C, Fan Z, Yang D, Zhang J, Meng F P and Wang L 2016 Technical advantages and market analysis of inorganic ceramic membranes Shandong Ceram. 39 6-9.
[4] Cheng X X and Liang H 2016 The development and prospect of ceramic membrane drinking water treatment technology J Harbin Inst Technol. 48 1-10.
[5] Zhang X S and Ni W H 2013 Current status and application of ceramic membrane development. Environ Eng 31 108-11.
[6] Zhu Y C 2011 Progress and application of commonly used ultrafiltration membrane combination process in drinking water treatment Water Purif Tech 30 72-75.
[7] Li M, Wu G and Guan Y 2011 Treatment of river water by a hybrid coagulation and ceramic membrane process Desalination 280 114-19.
[8] Konieczny K, Bodzek M and Rajca M 2006 A coagulation–MF system for water treatment using ceramic membranes Desalination 198 92-01.
[9] Shirasaki N, Matsushita T and Matsui Y 2009 Comparison of removal performance of two surrogates for pathogenic waterborne viruses, bacteriophage Qβ and MS2, in a coagulation–ceramic microfiltration system J. Membr. Sci 326 564-71.
[10] ZHANG J, DONG Q, SUN Y X, LIU X Q and MENG G Y 2006 Treatment of cathodic electrophoretic paint wastewater by coagulation-ceramic membrane microfiltration Membr Sci Tech 6 57-60.
[11] Watanabe Y, Kimura K and Suzuki T 1999 Membrane application to water purification process in Japan - Development of hybrid membrane system Water Sci Technol 41 9-16.
[12] Schlichter B, Mavrov V and Chmiel H 2003 Study of a hybrid process combining ozonation and membrane filtration — filtration of model solutions Desalination 156 257-65.
[13] Lee H C, Jin Y P and Yoon D Y 2009 Advanced water treatment of high turbid source by hybrid module of ceramic microfiltration and activated carbon adsorption: Effect of organic/inorganic materials Korean J Chem Eng 26 697-01.
[14] GUO J N, ZHANG X H, HU J Y, WANG L Y, ZHANG J G and Shen D Y 2013 Effect of Ozone Oxidation on the Reduction of Turbidity in Drinking Water by Ceramic Membrane Ultrafiltration Process J Environ Sci 33 968- 75.
[15] Athanasekou C P, Moustakas N G and Morales-Torres S 2014 Ceramic photocatalytic membranes for water filtration under UV and visible light Appl. Catal. B, environ 178 12-19.
[16] Romanos G E, Athanasekou C P and Likodimos V 2013 Hybrid Ultrafiltration/Photocatalytic Membranes for Efficient Water Treatment Ind. Eng. Chem. Res 52 13938-47.
[17] Kumakiri I, Diplas S and Simon C 2011 Photocatalytic Membrane Contactors for Water Treatment *Ind. Eng. Chem. Res* 50 6000-08.

[18] Ohno T 2004 Preparation of visible light active S-doped TiO2 photocatalysts and their photocatalytic activities *Water Sci* 49 159-62.