IOP Conf. Series: Materials Science and Engineering **392** (2018) 022036 doi:10.1088/1757-899X/392/2/022036

Development of flat ceramic membrane technology on municipal wastewater treatment

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Abstract: Water resource shortage and pollution have become a bottleneck which restricted social progress and economic development of China. The amount of municipal wastewater is large but its pollution is relatively light, so it has a significant potential for water recovery and recycle from municipal wastewater. As a novel water treatment technology, membrane separation has many advantages such as better water quality of effluent, lower operating cost and less land occupation. The flat ceramic membrane is a promising technology with an outstanding membrane structure and material, can not only realize the industrial wastewater treatment and reclaim, but also solve the problem of municipal water shortage and sewage discharge. In this review, the classification, characteristics and mechanisms of ceramic membrane were introduced firstly. Then the development of flat ceramic membrane technology and the coupled pretreatment units with the membrane in municipal wastewater treatment were discussed. And finally, the prospect of ceramic membrane technology for municipal wastewater treatment and recovery was also proposed.

1. Introduction

With the accelerated process of industrialization and urbanization, the consumption of industrial and domestic water has increased greatly in the past decade. The total water consumption in China [1] got to 604 billion and 20 million m^3 in 2016. And, the contradiction between the water resources shortage and the huge demand of society would continue to be intensified. Therefore, to develop the advanced wastewater treatment technology, can not only reduce the discharge of wastewater effectively and protect the water environment, but also save water resources and promote the development of ecological civilization.

In recent years, the capacity of urban sewage treatment in China has improved, but the overall treatment ratio was still less than 90%. Moreover, with the development of industry, the continuous inflow of industrial water has made the quality of municipal sewage became more complex [2]. Therefore, the challenges and issues brought by this complex industrial situation should be paid more attention to.

The membrane separation technology has chosen permeation membrane as the separation medium, the components of the raw water has selectively permeated through the membrane by applying a certain propelling force on both sides of the membrane, in order to achieve the purpose of separation and purification. It has the advantages of low energy consumption [3], high efficiency [4] and convenient operation. At present, the research and applications of membrane technology have been still dominated on organic membranes. Although the cost is relatively low, it still has some limitations such as poor corrosion resistance and oxidation resistance [5], low mechanical strength and short service life [6], which limit the long-term stable operation in the severe conditions and also restrict its combination with various pretreatment processes. For this reason, researchers have begun to focus on the application of inorganic membrane such as ceramic membrane in water treatment.

Based on this, the article would summary and discuss the classification, characteristics, filtration mechanism and the progress of ceramic membrane technology application in municipal wastewater treatment, furthermore，the prospect and research direction of ceramic membrane in the field of municipal wastewater treatment are also mentioned.

2. Overview of flat ceramic membrane

2.1. The classification of flat ceramic membrane

The pressure-driven membrane can be divided into microfiltration membrane(MF), ultrafiltration membrane (UF), nanofiltration membrane (NF) and reverse osmosis membrane (RO) according to the different pore size [7](shown in Table 1). The ceramic membrane used in water treatment mainly included MF, UF and NF.

Table 1. The classification of ceramic membrane.

The types of membrane	Average Pore Size
Microfiltration membrane(MF)	0.1-10μm
Ultrafiltration membrane（UF）	2-100 nm
Nanofiltration membrane（NF）	0.1-2 nm
Reverse osmosis membrane（RO）	<1 nm

2.2. The characteristics of flat ceramic membrane

As a rapidly developing new technology, the advantages of ceramic membrane are mainly manifested in [8]: 1) Good chemical stability. The ceramic membrane could withstand the microbial erosion and chemical corrosion such as acid, alkali, oxidizer and organic solvent; 2) Nice thermal stability. The ceramic membrane can resist high temperature below 1000 °C; 3) High mechanical strength. The ceramic membrane has a strong structural integrity and avoids repeating maintenance work of membrane module. 4) It was easy to clean and regenerate. The ceramic membrane could be cleaned by combined reagent included hot acid, alkali and oxidizing agent, even sustained to be regenerated by high temperature roasting. The high cleaning efficiency reduced the downtime for cleaning the membrane module. 5) Long service life. The ceramic membrane has a longer service life, a shorter replacement period and a lower running cost. However, there are still many restrictions on ceramic membrane, such as poor toughness [9], brittle and fragile characteristics, lack of ability to assist thermal shock and complex manufacturing process. These factors restrict the application of ceramic membrane in the field of water treatment.

2.3. The filtration mechanism of flat ceramic membrane

MF and UF are the most widely technology of ceramic membrane water treatment, which can intercept most of the suspended matter in water such as particles, colloids, microbes and macromolecule organic matter but the removal effect of dissolved molecule organic matter is limited [10], the filtering mechanism is generally divided into 3 kinds：1) Sieving effect. It means that the particles, microorganism and macromolecular organic matter with the larger pore size would be trapped on the membrane surface [11]; 2) Adsorption. The pollutants are adsorbed on the surface and the pores of the ceramic membrane by van der Waals force and the force of chemical bond or electrostatic, the pollutants can also be removed even if the particle size is smaller than the pore size of the membrane [12]; 3) Bridging action. The interaction between pollutants could be integrated, thus being filtered by ceramic membrane.

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3. Application of ceramic membrane technology in municipal wastewater treatment

The practical application of the flat ceramic membrane is usually associated with the pretreatment technology. The technology of treating municipal wastewater with flat ceramic membrane will be classified according to different types of pretreatment technology.

3.1. Coagulation pretreatment

Many scholars selected the coagulation technology as ceramic membrane pretreatment unit because of its lower cost and easy operation. Coagulation pretreatment makes the pollutants in water gather to form larger particles, thus it is beneficial to the effect of the subsequent removal process. Zhang [13] studied the influence on MF ceramic membrane by different coagulant pretreatment. It was found that the membrane fouling was effectively alleviated with 4 kinds of coagulants such as aluminum sulfate, aluminum chlorohydroxide (ACH), iron sulfate and ferric chloride. From the comparison between reducing effect of membrane fouling and economy cost, ACH was selected as the best coagulant. The research of Li [14] also showed that the flux of ceramic membrane increased significantly after coagulation pretreatment of poly aluminum chloride (PAC). Matsushita [15] investigated the effect of virus removal efficiency by different coagulant dosage, average pore size of ceramic membrane and coagulation time. It was found that the virus removal efficiency enhanced with the augment of coagulant dosage and coagulation time but reduced with the increase of membrane pore size. All of the factors such as coagulant type, dosage, coagulation time and characteristics of the membrane have a certain influence on the performance of the process, therefore optimization of working conditions should be determined by combining with the water quality of the original water. It should be noted that excessive dosage of coagulant would lead to residual in water, which may aggravate membrane fouling [12].

3.2. Adsorption pretreatment

The mechanism of adsorption pretreatment is that the dissolved organic matter in water is adsorbed by adsorbents, and then adsorbent particles would be intercepted by ceramic membrane, so as to achieve the removal of pollutants. In the field of water treatment, the research of activated carbon is most widely and thoroughly. Oh [16]adopted integrated process of powdered activated carbon (PAC) and MF ceramic membrane to treat polluted water, the water purification effect was significantly better than the traditional ozone-GAC process, the removal efficiency of UV260 and DOC were 90.3% and 80.2% respectively, besides, there were no bacteria and viruses were detected.

3.3. Oxidation pretreatment

Oxidation pretreatment mainly make use of the oxidizing agent such as chlorine [17], Potassium Permanganate [18], ozone [19] and UV [20] to inhibit the microbial growth in water, or change the structure and properties of organic pollutants to achieve the purpose of purifying the water quality. Karnik [21] used integrated process of ozone and membrane combination to treat surface water, the growth potential of DOC, UV254, trichloromethane and haloacetic acid decreased significantly. Kim [22] studied the influence on the flux of UF ceramic membrane and concluded that the higher the ozone dosage and the smaller the transmembrane pressure are, the slower the membrane flux decline. In addition, Zhang [20] experimented with UV/H_2O_2 oxidation pretreatment to alleviate the MF ceramic membrane fouling caused by AOM. It was shown that UV/H_2O_2 oxidation pretreatment had the same alleviating effect of membrane fouling as ACH coagulation pretreatment. But the irreversible pollution was serious, it was mainly due to the small molecule organic matter in the process of oxidation would plug membrane hole and induce more irreversible pollution.

3.4. Biological oxidation pretreatment

The new technology of ceramic membrane separation has been researched since 1940s. The ceramic membrane bioreactor has developed in recent years because the advantages included compact structure, low sludge production and excellent water quality. Xv [23] adopted tubular ceramic membrane bioreactor for domestic sewage treatment. The results showed that the removal efficiency of COD_{Cr}, ammonia nitrogen and suspended solids were 99.5%, 99.9% and 100%. The water quality of the effluent completely got the standard of reclaimed water. Zhang [24] also achieved good effect on ceramic membrane bioreactor for municipal wastewater with low speed of flood. Xing [25] manufactured a inorganic membrane bioreactor (IMBR) to treat the domestic sewage. In the end, the removal efficiency of COD, NH3-N and turbidity were more than 96%, 95% and 98% respectively. Especially, all of the SS and Escherichia coli were removed, and the quality of effluent was stable.

4. Conclusion

Above all, the suggestions were proposed: 1) Preparation technology of ceramic membrane should be optimized to reduce the cost of membrane production. High price has always been the most important factor which restricted the practical application of ceramic membrane. Therefore, it is beneficial to the market promotion of ceramic membrane technology by innovating the relative technology and decreasing the production costs. 2) Controlling the membrane fouling in order to prolong the service life of ceramic membrane as far as possible. The pollution of membrane not only affected the water treatment effect, but also increased the operating cost. Although the ceramic membrane technology for municipal wastewater treatment has been paid more attention, the research on ceramic membrane fouling was relatively few. It will become the research emphasis in the future that explore the mechanism of membrane fouling and select suitable membrane cleaning methods on the purpose of delaying membrane aging. 3) Research on integrated equipment. With the improvement of life quality, it was the inevitable trend included integrated technology, processing equipment, automatic operation, upscale water quality. Many wastewater treatment plants need to upgrade and remould, the constraints of the site increase the limitations of technical selection, it is urgent to develop the advanced technology for municipal wastewater treatment.

Acknowledgement

This work was financially supported by the National Science Foundation of China (51678276), the key research and development program of Shandong Province (2016CYJS07A03-3, 2016GSF117012, 2018GSF117026) and the Shandong Provincial Natural Science Foundation (ZR2018BEE040).

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