Application of Ultrafiltration Technology in Water Treatment

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Abstract: The sustainable utilization of water resources is the support for the sustainable development of the economy and society. In recent years, with the increasing shortage of water resources in the process of economic development, various kinds of new, improved and highly efficient water treatment technologies has emerged. However the ultrafiltration technology has shown great potential in various fields of water treatment for its features such as low energy consumption, simple structure, less land occupation, convenient operation and easy to realize automation, etc, and it has been widely used. This article, which elaborates on the development history, concepts, principles and advantages of ultrafiltration technology, analyses the research situation as well as the application status in the water treatment industry at home and abroad for the past few years and discusses the existing problems.

1. Introduction
With the development of economy and the progress of society, people's living standards are constantly improving, and the impact of human activities on the environment is also expanding, resulting in increased environmental pollution. Among them, water pollution cannot be ignored. Unlike energy, water can be created and destroyed. (Probably some of us can remember a simple experiment from our school days where a battery is attached to two electrodes that are plunged into a glass of water. Likewise, burning any hydrocarbon creates water.) But outside of a science lab, water should be treated as a finite and precious resource. In view of the shortage of water resources, it has emerged various kinds of new, improved and highly efficient water treatment technologies. Ultrafiltration (UF) technology is the most common application in different water treatment technologies. The UF has the characteristics of less land occupation, stable water quality and high automation. In addition it’s capable of almost removing microorganisms completely from the water, greatly improving the biosafety of water, for the virus, colloidal substances and suspended particles inside the water can be fully filtered. As the core technology of the third generation of urban drinking water purification technology, ultrafiltration will become a new direction of urban drinking water purification process and it is also of great potential in the recycling of domestic sewage and industrial wastewater. Compared with the traditional water treatment process, the UF technology has higher processing efficiency, better treatment effect and lower energy consumption. It is significant to further investigate on ultrafiltration technology for improving water quality, protecting water resources and ecological environment.

2. UF development history
In 1861, Schmidt successfully completed the ultrafiltration experiment with a natural bovine pericardium for the first time in the laboratory. Although the term “ultrafiltration” was first proposed
in 1906 by Becchhold et al. for more than 100 years, the first real ultrafiltration membrane was born in the early 1960s [5]. In 1970s, with the advent of various kinds of new materials, ultrafiltration membranes quickly got into commercial. The initial application of ultrafiltration technology was in the chemical and pharmaceutical industries. It was not until the 1990s that the water treatment industry was able to develop rapidly. As of now, ultrafiltration is widely used in various fields, such as ultrapure water preparation in the electronics industry, electrophoretic paint recycling, beverage and juice production, food industry water, pharmaceutical industry, medical industry, and wastewater treatment and recycling, etc [6-10]. In 1970s, our country began to study the ultrafiltration membrane. In 70s, the cellulose acetate membrane ultrafiltration membrane was successfully developed, and the polysulfone hollow fiber ultrafiltration membrane was successfully developed in 80s. At the same time, encouraging progress has been made in the charge membrane, film formation mechanism and membrane fouling mechanism. China has PS, PAN, PSA, PP, PE, PVDF and more than ten varieties of ultrafiltration membrane by far [11].

3. UF concept, principle and advantages

3.1. Concept

At the beginning of the 20th century, Becchhold first proposed the concept of ultrafiltration [12]. Ultrafiltration (UF) is a membrane separation technology that separates, purifies, and concentrates solutions between microfiltration and nanofiltration. Its definition domain is to intercept the molecular weight 500~500000 Da. The approximate diameter of the corresponding aperture is about 0.001~0.1μm, the operating pressure difference is generally 0.1~0.8MPa, and the diameter of the separated component is about 0.005~10μm [13].

3.2. Principle

The schematic diagram of the ultrafiltration process is shown in Figure 1. The process can be understood as taking the pressure difference between the two sides of the membrane as the driving force. Under the impetus of static pressure, using ultrafiltration membrane as the filter medium, the solvent in the raw material liquid and the small-molecular-weight solute with smaller pore diameter pass through the ultrafiltration membrane from the high pressure side to the low pressure side, while the large molecular weight solutes are trapped on the high pressure side. That is to say, when water flows through the membrane surface, only water, inorganic salts, and small molecular substances are allowed to permeate the membrane, preventing the passage of macromolecules such as suspended solids, colloids, proteins, and microorganisms in the water for achieving the purpose of purification, separation, and concentration of the solution [10, 13, 14]. Physical screening is generally considered to be the main retention mechanism of ultrafiltration membranes. However, sometimes the pore size of ultrafiltration membranes is larger than that of solvents and solute molecules. It should not have trapping effect, but it actually has obvious separation effect. This may be the chemical properties of the membrane surface, such as the cause of electrostatic effects. In summary, there are three main mechanisms of ultrafiltration membrane retention: adsorption once on the surface of the membrane and in the pores, retention in the pores, and removal of mechanical pores on the surface of the membrane [15].
3.3 Superiority

Compared with conventional process, UF process has the following advantages: (1) The turbidity rate is high as well as the filtration accuracy, the effluent water quality is stable and reliable, the water quality index changes little, and it is affected little by other factors. In the removal of turbidity and particulate matter, the UF process has a higher removal rate than the conventional process, the effluent turbidity is stable below 0.1 NTU, and the removal rate of particulate matter is up to 99.9%. (2) It can effectively remove pathogenic microorganisms. The UF technology is able to effectively remove pathogenic microorganisms and pathogenic viruses such as Giardia, Cryptosporidium and bacteria in water\[16\]. In fact, UF membranes are able to achieve values of 7 log in reduction of total coliform bacteria, 4.4–7 log removal for Cryptosporidium, 4.7–7 log removal for Giardia lambia and 6 log or higher for some viruses as MS2 bacteriophage\[17\]. (3) The process is streamlined. Ultrafiltration effluent turbidity is in a position to be reduced to 0.1 NTU, and has nothing to do with water turbidity before ultrafiltration. Therefore, the water after coagulation and sedimentation can be directly carried out for ultrafiltration without conventional filtration\[18\]. The effluent after ultrafiltration is not required to be reinjected and does not need to add other chemical agents, simplifying the process flow and realizing the automation control of the water plant. (4) Small area of water works. The surface area of the ultrafiltration process is only about 1/5 of the traditional process\[19\]. (5) Ultrafiltration process saves water cost relative to conventional plus advanced treatment process.

Fang\[20\] uses an integrated water purifier to treat the Yangtze River water with pretreatment and ultrafiltration process, producing a large amount of water; at a flow rate of 16.83 to 17.67 L/min, the flow rate of the effluent is 15.00 to 16.40 L/min. Equivalent to 89%–93% of influent water flow, the water quality is good and the whole device covers an area of about 1.28m², which saves a considerable amount of floor space compared to the traditional process. Wu et al.\[21\] found that UF's domestic water production cost was 0.23 yuan/m³, and electricity consumption was 0.18 kW/m³. The research of Shenzhen water group shows that adding ozone and activated carbon advanced treatment technology on the basis of conventional process will increase the water production cost by 0.3 yuan /m³. These studies show that the water cost of the ultrafiltration process is lower than that of the conventional process.

4. Application status of UF

The application of ultrafiltration technology has been more than forty years ago. In recent years, ultrafiltration has been widely used in the fields of water treatment, such as drinking water purification, wastewater treatment, industrial wastewater treatment, seawater desalination, and water reuse. In the field of ultrafiltration membrane research and application, Japan and the United States are in the leading position.
4.1 Drinking water purification

The quality of drinking water directly affects people's health. The suspension of water, bacteria, viruses, heavy metals, fluoride, chlorides, disinfection byproducts and pesticide residues are all likely to pose a threat to health. In the aspect of water purification, ultrafiltration technology can remove suspended solids, bacteria, viruses, etc. in water[22]. Ultrafiltration can remove almost all bacteria, viruses, "two pests", algae and aquatic organisms, and is the most effective technology to guarantee the microbiological safety of water at present. In the United States, Japan and other countries, priority is also given to the use of ultrafiltration membranes for urban waterworks[4]. The use of ultrafiltration could almost completely remove microorganisms from the water, greatly improving the biological safety of water, and will inevitably cause a major change in the purification process of drinking water[3].

UF technology was originally used in the chemical and pharmaceutical industries and was used in drinking water treatment in the 1980s[23]. Since 1988, after the construction of the world's first municipal water supply ultrafiltration water plant (2300m³/d) in Bernay, France[24], ultrafiltration technology, as the core technology of the third generation urban drinking water purification technology, has been widely used in the field of water treatment[4, 23].

In the treatment of drinking water sources, the single ultrafiltration technology is not very effective, and combined with other processes can show good performance. Zhang et al.[27] used ultrafiltration depth processing technology to treat the source water of a river in Jiangsu. The results show that the turbidity of water after treatment is below 0.1NTU and does not change with the change of water quality, and the removal rate of CODₘₙ is 44%. The average CODₘₙ concentration of the effluent meets the requirements of GB5749 - 2006 Drinking Water Hygiene Standard, only 2.5mg/L; the removal rate of UV₂₅₄ and DOC in the whole process is 18% and 24% respectively. However, ultrafiltration did not contribute much to the removal of UV₂₅₄ and DOC, mainly because the UF did not work well for soluble organic matter.

The combination process of ultrafiltration has an unparalleled advantage in improving the removal rate of small molecule organic matter and reducing membrane fouling. Many experts and scholars have also studied the combination process of ultrafiltration and other processes to improve the removal effect of this kind of contaminant. Among them, powdered activated carbon ultrafiltration (PAC-UF), coagulation and ultrafiltration combined technology have been widely studied at home and abroad, and some achievements have been made. H.Klaus[28] proposed that a certain amount of powdered activated carbon (PAC) be added to the circulating water stream of an ultrafiltration membrane device to constitute an adsorption-solid-liquid separation process for treating drinking water. In theory, dissolved organics in water can be adsorbed by PAC, and ultrafiltration membranes can completely retain PAC particles. Therefore, PAC adsorption can enhance the retention of dissolved organics in the ultrafiltration membrane and reduce membrane fouling. Chen[29] used PAC-UF combination process to perform advanced treatment of conventional process water. The test results show that the removal rate of UV₂₅₄ is doubled than in a single ultrafiltration process, while the removal rate of CODₘₙ increases by nearly 4 times. At the same time, the study shows that the PAC-UF combination process can effectively control the growth of cross mold pressure difference, effectively reduce the pollution of the super membrane, and also have obvious removal of a class of small molecular substances represented by the precursors of macromolecular organic matter and disinfection by-products. Some foreign scholars also use magnetic activated carbon to replace the traditional activated carbon, which is not only beneficial to the recovery and utilization of activated carbon, but also to avoid the problems of carbon agglomeration and pipeline blackening[30]. Although there are many advantages of the PAC-UF combination process, the problem of the recovery and dosage of powdered activated carbon needs further research in order to make the actual operation more refined[31].

The combination of ultrafiltration and coagulation is also a widely used process. Adding coagulation process before the ultrafiltration process can enhance the removal efficiency of small molecule organic and dissolved pollutants, alleviate membrane pollution and maintain high membrane flux. Zhang et al.[32] used the coagulation sedimentation as a pretreatment method to conduct a pilot
plant experiment to study the optimal operation mode of immersed ultrafiltration membranes for treating Dongjiang water. The process can reduce the content of the process by setting up multi-level barriers to pathogenic microorganisms, turbid substances, natural organic substances, toxic and harmful trace organic pollutants, ammonia nitrogen, and heavy metals in water. Dixon et al. [33] have found that coagulation can reduce membrane fouling, improve membrane filtration performance, and enhance water treatment. The use of coagulation as a pretreatment can complement the ultrafiltration process. This combination process is widely used. In the future, new coagulants should be considered to reduce membrane fouling and increase treatment efficiency.

4.2 Urban sewage reuse
Urban sewage is an important water resource. Membrane technology has been used for many years, and has been widely promoted in China. The reverse osmosis process is often used in some places where the demand for water reuse is high, such as the salinity of the reclaimed water, and the final treatment of the waste water is often needed. Ultrafiltration as a pretreatment of reverse osmosis(RO) has a wide range of applications in the field of wastewater reuse. For example, the currently popular double-membrane technology (UF + RO) is often used to recycle wastewater, and the effluent can be used as a recycle. Supplementary water for cooling water or production process water [23]. Ultrafiltration technology can remove the fine particles that cannot be removed in the biochemical treatment process, and can generally be used for further advanced treatment after secondary biochemical treatment of the sewage. In practical applications, the ultrafiltration system, as a follow-up processing unit, has undergone different engineering practices by combining with the current biochemical treatment process to form a more efficient treatment process, with high degree of automation, stable treatment effect, and reliable effluent quality etc. [34]

4.3 Desalination of sea water
Desalination has become an important way to alleviate the shortage of water resources. Ultrafiltration is more used as a pretreatment technology for seawater desalination, especially reverse osmosis technology for seawater desalination pretreatment. Sun et al. [35] adopts different ultrafiltration systems, including continuous membrane filtration system (CMF), immersion membrane filtration system (SMF), ultrafiltration and traditional pretreatment methods, and direct ultrafiltration, to explore an effective pretreatment method with ultrafiltration as the core serves as a seawater desalination pretreatment process in Bohai Bay. The results show that, although the test site and the influent water quality are different, the ultrafiltration membrane module can provide a good water supply for the reverse osmosis system. Li et al. [36] explored the performance of ultrafiltration membranes in the seawater desalination pretreatment process. The experimental results verified the performance of the ultrafiltration module, optimized the seawater desalination ultrafiltration pretreatment process, and provided stable and reliable influent water for the reverse osmosis unit.

4.4 Industrial wastewater treatment
With the rapid development of global industrialization, more and more attention has been paid to how to improve the level and efficiency of industrial wastewater treatment and alleviate the pollution of wastewater. Compared with the conventional wastewater treatment, the membrane integrated technology has the advantages of small wastewater treatment equipment, simple operation, low operating and maintenance costs, excellent operating environment, high treatment efficiency and strong sewage purification capacity. In addition, the chroma removal rate of the square mask technology is superior to that of the conventional method. Therefore, membrane integration technology is widely used in the treatment of industrial wastewater. Ultrafiltration technology has good technical advantages and application space in the advanced treatment process of printing and dyeing wastewater, papermaking wastewater, oily wastewater, heavy metal wastewater, and food wastewater. Debik et al. [38] studied the ultrafiltration/nanofiltration (UF-NF) double-membrane integration technology for the treatment of printing and dyeing wastewater, and discussed the effects
of pretreatment processes, throughput, and water quality treatment. The results show that the use of ultrafiltration/nanofiltration double membrane integrated technology can obtain higher water flux than single nanofiltration technology, and the indicators such as chemical oxygen demand (COD) colorimetric and electrical conductivity of wastewater after treated by ultrafiltration/nanofiltration double membrane integrated technology all meet the water quality requirements for printing and dyeing wastewater. Zhou et al. [39] used membrane integration technology to treat emulsified oil wastewater. The experimental results show that the COD removal rate of the emulsified oil wastewater after treatment is above 95%, and the flux recovery rate after membrane cleaning is above 95%. Wang et al. [40] developed an ultrafiltration-reverse osmosis-ion exchange membrane integrated technology system for advanced treatment and resource utilization of industrial wastewater containing colloidal heavy metal (Cu²⁺).

5. Conclusion
Ultafiltration technology is about to be widely used in various fields of water treatment around the world. Since physical screening is the main retention mechanism of ultrafiltration membranes, this technology is in line with the concept of green technology and can improve the utilization of energy and resources. Although membrane life and membrane fouling are still important constraints, with the continuous improvement of membrane assembly processes, membrane materials, membrane modules, system design, and operation and maintenance technologies, ultrafiltration technology will surely become more widespread in the field of water treatment applications.

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