Characteristics of Traditional and Emerging Water Treatment Technologies and Their Comparison

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Abstract. With the growth of urbanization and industrialization in the world, excessive water pollution has led to water scarcity as one of the most important problems today. Therefore, how to purify water resources has become the main way to solve the freshwater problem, and the water treatment process is the main way to purify water resources. This article investigates the traditional technologies represented by biofilm and activated carbon technologies, and the emerging technologies represented by ozone oxidation, photocatalytic oxidation and membrane separation technologies, comparing and summarizing their principles, advantages and disadvantages, and application scope. The study finds that traditional technologies like activated carbon technology have the advantage of being inexpensive, low cost and technologically mature. However, they often produce secondary pollution and cannot be reused, leading to the fact that traditional technologies alone are not suitable for water treatment in today's society. As for emerging technologies such as photocatalytic oxidation, although they have solved the problems of secondary pollution and high efficiency of traditional technologies, they are also due to the high infrastructure cost to limit the pace of their promotion in water treatment plants. Therefore, by comparing and contrasting the advantages and disadvantages of these technologies and their scope of application, this article hopes that the technologies can be combined to realize the purpose of promoting them in water treatment plants, thus purifying water resources and alleviating the problem of water scarcity in today's world.

Keywords: Water treatment technology, Ozone oxidation technology, Photocatalytic oxidation technology, Membrane separation technology.

1. Introduction

Currently, water scarcity is a significant issue facing the planet today. Although the Earth has an abundance of freshwater resources, most of them are in the polar regions. As a result, very few water resources are available for human consumption. In addition, with the development of urbanization and the increase in population, the discharge of many industrial wastewater that is untreated or not treated to the required standard, as well as the indiscriminate discharge of agricultural wastewater, have led to the deterioration and shortage of water resources. Therefore, the water treatment has become an important part of water conservation.

Since the beginning of the last century, the water treatment process has received extensive attention worldwide. As early as the 1960s, some European countries began to use bio-activated carbon technology for the deep treatment of wastewater. Similarly, the technology has been developed in China for over 30 years [1]. Bioremediation technology has been used with large-scale environmental pollution treatment since the 1980s [2].

So far, as more and more people are aware of the scarcity of water resources and the importance of water treatment, more and more water treatment technologies have been researched and more technologies are coming to maturity. However, many of today's studies only analyse a single process, and there is a lack of comparisons and summaries between traditional and emerging technologies. In this paper, we choose biofilm technology and activated carbon technology as the representatives of traditional technology and ozone oxidation technology, photocatalytic oxidation technology and membrane separation technology as the representatives of emerging technology, analysing and comparing their characteristics, advantages and disadvantages, and scope of application, elucidating the problems of each of them.

2. Traditional Technology

2.1. Biofilm Technology

Biofilm technology uses the metabolic activity of living organisms to place toxic and harmful pollutants, causing the pollutants to be absorbed, degraded or converted into harmless substances, thus making the polluted ecosystem wait for the restoration of the technology. The essence of the biofilm method is to make microorganisms, and microfauna adhere to the surface of the carrier, gradually forming a membrane-shaped active biological sludge, biofilm microorganisms in the process of consuming water pollutants [3].

Biofilm technology is relatively resilient. Cells immobilized by biofilms are less likely to be ingested by large aquatic animals due to the protective effect of the biofilm matrix. At the same time, microorganisms with diversity can synergistically increase the tolerance of biofilms to the external environment, thus enhancing their resistance to harsh environments [2,3]. In addition, it is more capable of removing pollutants. Its more stable internal environment allows bacteria or miniature metazoans with a relatively long growth generation time to have some time to grow in abundance, making the removal of pollutants by microorganisms more effective [2]. In addition, a large number and variety of microorganisms can enhance its ability to absorb pollutants and purify wastewater [3].

The complexity of the natural environment leads to slow reproduction of microorganisms and thus lower numbers, hence poor biofilm stability. Eventually, the decontamination effect will be significantly reduced [2].

In recent years, the United States, Germany and other developed countries have biofilm purification technology applied to small river projects and has achieved specific results. In China, the technology is mainly applied to in situ remediation of polluted rivers [2].

2.2. Activated Carbon Technology

Activated carbon technology involves the preparation of activated carbon that produces many different shaped pores that interact (e.g., activated carbon interacts through physical adsorption, chemical adsorption, exchange adsorption, and catalytic oxidation) to remove pollutants from water [4].

As a common adsorbent, activated carbon has the advantages of high adsorption capacity, wide source of raw materials and low cost [1]. It is characterized by a large surface area, well-developed pores and high cavity capacity when it comes to the adsorption of heavy metal ions [4]. In addition, the surface of activated carbon is also stable and tunable, and the oxygen- and nitrogen-containing functional groups on the surface of activated carbon are capable of changing the chemical properties of metals [4].

However, activated carbon has more application problems because it tends to adsorb to saturation, after which its adsorption capacity decreases significantly. Moreover, its saturated activated carbon is also difficult to treat, increasing the cost of treating the pollutant. Currently, activated carbon is often combined with microorganisms to form bio-activated carbon, which improves adsorption capacity and reuse possibilities.

3. Emerging Technology

3.1. Ozone Oxidation Technology

Ozone oxidation refers to the combination of oxidants and ozone, where an oxidation-reduction reaction occurs to produce strongly oxidising hydroxyl radicals, which decompose the pollutants in the wastewater into carbon dioxide, water and inorganic salts, amongst others.

Ozone has strong oxidising properties and is currently used as a strong oxidising agent in water treatment. When ozone is in an alkaline environment, OH- can accelerate the decomposition of ozone and produce a large number of reactive radicals with strong oxidizing properties [5]. It has a broad inactivating effect on microorganisms and a high disinfectant capacity, 10 times more effective in inactivating poliovirus than an equivalent chlorine disinfectant [6]. Ozone oxidation is widely used in drinking water treatment. As the quality of drinking water improves and the level of contamination of raw water increases, it is also used as a feedwater pretreatment to reduce molecular weight and improve the removal of organic matter in conventional treatment processes [6].

However, the ozone oxidation process is energy-intensive and costly for wastewater treatment, so it is usually used in conjunction with other process technologies. For example, ozone-bioactivated carbon technology is now widely used as a deep treatment technology for feed water [6]. In this technology, the substantial oxidizing property of ozone can be used to effectively remove impurities, such as water odor, ammonia and nitrogen, and algal toxins, while destroying the structure or functional groups of organic molecules and lowering the molecular weight [6]. The technology is relatively mature, experienced in management, and has a high capacity for operational stability [6].

3.2. Photocatalytic Oxidation Technology

Photocatalytic technology is one of the advanced oxidation methods. It is a class of technology that utilizes the strong oxidizing ability of hydroxyl radicals and superoxide radicals to achieve wastewater treatment by rapidly reacting with organic pollutants to degrade them upon contact [7]. The reaction process photocatalysis generates free radicals followed by a series of chain reactions until the organic pollutants are converted to the final pollutants, carbon dioxide and water [7].

It is an efficient, energy-saving and secondary pollution-free water treatment technology [8]. This technology has the advantages of mild reaction conditions, i.e., it can generally be realized under conventional conditions, low energy consumption, i.e., solar energy can be utilized as a light source, and easy operation [8]. Compared with the traditional water treatment process, it has greater advantages in the problematic aspects of deleting organic matter, micro-polluted organic matter and drinking water [8]. In addition, photocatalysis also has the ability of deodorization and disinfection, which can not only inactivate bacteria and viruses, but also decompose them, so as to avoid the release of toxic components after the death of microorganisms in the water, which will cause secondary pollution [8]. Additionally, the whole process in this reaction takes less time, and the reaction conditions are easy to control, with better processing advantages and application advantages [5].

It has a wide range of applications and has been applied to treat coking, pesticide, dye, paper, oily, and drinking water [7,8]. It is suitable for treating difficult-to-degrade wastewater with low concentrations of organic matter and low turbidity [5].

The application of photocatalytic oxidation technology is mainly limited by catalytic materials, reactor design, installation and maintenance. For example, the catalytic activity and efficiency of a single photocatalytic material can be limited by the characteristics of the material itself, and the reactor design is not mature. This leads to low light utilization, difficult separation and recovery of catalysts, and therefore high operating costs. In addition, the installation and annual maintenance costs of photocatalytic materials are several times higher than those of conventional technologies [7].

3.3. Membrane Separation Technology

Membrane separation technology is a kind of use of special membrane has a selective through the sex, the use of membrane on both sides of a variety of differences, like liquid difference, solute concentration difference, and potential difference after energization as a driving force, so that the separation of the separation of different selective components through the membrane separation, so as to achieve the purpose of water purification [9].

The technology is characterized by high efficiency, low energy consumption and non-pollution because it does not require a regeneration step, is a simple process, has a small footprint and is an environmentally friendly operation with no secondary products and no waste generation [10]. Since no phase change occurs during the membrane separation process, all components of the substance to be separated remain in their original state. This means that this subsequent processing does not require additional energy consumption for reduction [9]. At the same time, the membrane separation technology has a wider range of scale and processing capacity, not only for the separation of solid solutes, the separation of nanoscale particles, the separation of organic and inorganic substances, but also for the separation of gases dissolved in solution [10].

Membrane clogging is the biggest problem of this technology, and the membrane separation technology requires high water quality, complex pretreatment of reaction water [9] and elevated costs. This makes some membrane separation applications not very widespread.

Membrane separation in environmental engineering water treatment is commonly used in drinking water purification, industrial wastewater treatment and recycling, seawater and other brackish water purification projects, pure water production and water reflux applications [9]. In addition, in recent years, the technology has also been widely used for gas separation in water purification and desalination or with dense polymer membranes as the separation layer [10].

4. Discussion

Table 1 shows a comparison and summary of traditional and novel techniques. Traditional technologies such as activated carbon adsorption and biofilm treatment have matured. However, their problems are becoming clearer and clearer at the same time, such as unavoidable secondary contamination, susceptibility to environmental influences, and mostly disposable purification methods.

These emerging technologies, like ozone oxidation, photocatalytic oxidation and membrane separation technology, are certainly more environmentally friendly, cleaner, free of secondary pollution, more thorough and efficient, and have a broader range of applications than traditional technologies. However, they tend to be more costly to disassemble, less technologically mature, and lack a number of practical problems to study. Moreover, these shortcomings are often the reason why they are not marketable or scalable.

In the future, we need to strengthen the innovation of traditional technology, combine traditional technology with emerging technology and learn from each other, so as to solve the problem of secondary pollution of traditional technology. Whereas in the case of emerging technologies, more research is needed on their market, reduce the cost of their infrastructure or replace high-cost components with better alternatives. The design of the reactor needs to be improved so that its maintenance costs can be reduced. In addition, in the process of the application of emerging technologies, it is also necessary to strengthen the research, give full play to the effective degradation of various pollutants by various technologies, and further optimize the reaction process. In the future, both traditional and emerging technologies will be better developed to cope with the increasing scarcity of water resources.

Currently, the combination of traditional and emerging technologies has yielded corresponding results. For example, biological activated carbon (BAC) technology combines the adsorption function of activated carbon and the decomposition function of biofilm. Activated carbon provides microorganisms with attachment sites and living environments, and can also alleviate the inhibitory effects of heavy metals on microorganisms. Microorganisms, on the other hand, biologically regenerate the activated carbon through the organic matter it adsorbs, prolonging the life of the activated carbon. Thus, its purification effect is much greater than the sum of both individual effects [1]. With the development of these technologies, wastewater treatment is more effective and more water resources can be more fully utilized.

Table 1. Comparison of traditional and new technologies for water treatment

	Principle	Advantage	Disadvantage
Biofilm Technology	Processes that utilize the metabolism of organisms to remove pollutants	Strong resistance, tolerance, wide range of decontamination, high capacity	Vulnerability to complex environments
Activated Carbon Technology	The process of adsorption of pollutants by activated carbon using pore sizes of different shapes and sizes.	High adsorption capacity, wide range of raw materials, high surface stability and adjustability, low cost	Easily saturated, difficult to recover and reuse
Ozone Oxidation Technology	Oxidize pollutants with ozone, eventually breaking them down into carbon dioxide and water	Strong oxidizing property, inactivation of microorganisms, strong disinfecting ability, deodorization	High cost of water treatment, lower reaction efficiency, high energy consumption
Photocatalytic Oxidation Technology	The process that utilizes photocatalysis to generate free radicals in a series of chain reactions, ultimately converting pollutants into carbon dioxide and water.	High efficiency, energy saving, no secondary pollution, easier to realize the reaction conditions, strong ability to degrade organic matter, deodorization and disinfection	High installation and maintenance costs due to limited photocatalytic materials and reactor design
Membrane Separation Technology	The process of purifying water by separating different components of wastewater using the selectivity of special membranes.	High efficiency, low energy consumption, simple operation, wide range of applications, no secondary pollutants	Influenced by the surrounding environment, difficult to solve membrane clogging

5. Conclusion

This paper discusses the principles, advantages and disadvantages, and application scope of two traditional processes, biofilm technology and activated carbon technology, as well as three emerging processes, ozone oxidation technology, photocatalytic oxidation technology and membrane separation technology, and analyzes and compares their various performances and characteristics.

The environmental impact of biofilm technology, which utilizes the metabolism of new organisms for water purification, is significant. When slight environmental changes occur, the technology utilizes its strong resilience and recovers itself. At this point, it outperforms other technologies. However, when the environment changes too much, the biofilm is harder to form or can be destroyed. At this point, it becomes weaker. Activated carbon technology is characterized by a wide range of sources, high adsorption capacity and low cost. However, its disadvantage is also pronounced, when it adsorbs saturation, it is difficult to reuse the substance. At the same time, the adsorption of saturated material also makes it difficult to degrade substances, and produce secondary pollution, increasing the water treatment cost.

Ozone oxidation technology utilizes the strong oxidizing properties of ozone, its broad inactivating effect on microorganisms, and its disinfecting ability to make water treatment more efficient and thorough. However, ozone alone is less effective in treating wastewater and often requires other reactants as well as other environmental conditions, making the reaction very costly. Photocatalytic oxidation technology is characterized by high efficiency, energy saving, no secondary pollution, and treatment of many difficult-to-degrade organic pollutants. However, when photocatalytic oxidation technology is applied, the high infrastructure cost and annual maintenance fee limit its popularization and application. For membrane separation technology, its reaction process does not produce phase change and the wide range of pollutants to be treated, which makes it characterized by high efficiency and low energy consumption. However, the difficult-to-solve membrane clogging problem leads to limited applications.

Consequently, traditional technologies need to be combined as a way of building on their strengths and avoiding their weaknesses. Moreover, emerging technologies need to consider how to promote the technology, so that these technologies in water treatment are fully applied. When these water treatment technologies are fully developed, the lack of water resources in the world can be alleviated to a certain extent, thus protecting the world's water resources.

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