Influencing Factors of biofilm nitrification in long-distance water pipeline

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Abstract. The long-distance water transfer project alleviates the situation of water supply tension in various parts of China. In the process of raw water transportation, the nitrification reaction will be carried out by microorganisms due to the existence of a pipe wall biofilm, which converts ammonia nitrogen in water into nitrite nitrogen and nitrate nitrogen. Nitrification of pipeline biofilm is affected by many factors, including temperature, dissolved oxygen concentration, nutrient content, type, and concentration of disinfectants. These factors can change the activity, quantity of nitrifying bacteria, and the conversion rate of ammonia nitrogen, which leads to the effect of nitrification.

1. Introduction

With the uneven distribution of water resources and the aggravation of water source pollution in some areas, long-distance water transfer projects have emerged, such as "south to North Water Transfer" and "diverting Luanhe River into Tianjin". Owing to the long-distance transportation in water diversion project, the safety of water quality in the pipeline has been threatened. For a long time, biofilm polymer will grow on the wall of the water pipe, which is composed of bacteria, organic matter, and inorganic substances suspended in water. The biofilm of the water pipeline refers to a kind of polymer formed by the microorganism, organic matter, and inorganic substance suspended in the water under the action of water flow and adhering to the pipe wall during the long-distance water delivery process.

As a result of the rapid change of the natural environment and the artificial development of industrial agriculture and other reasons, the concentration of ammonia nitrogen in water has shown an upward trend in recent years. However, the conventional "coagulation-sedimentation-filtration-disinfection" process cannot effectively remove ammonia nitrogen economically. The biological pre-treatment process device and filler designed by the water plant are expensive, which will aggravate the operation load of the water plant. The long-distance water pipeline is equivalent to a biological pre-treatment reaction device. Nitrifying bacteria can make full use of the vast surface area of the inner wall of the pipeline and the long-distance water transportation process, thus reducing the load of conventional treatment in water plants.

The microorganisms in the water pipeline mainly gather on the biofilm on the pipe wall, so the nitrification of the biofilm is the main way to remove ammonia nitrogen in the water. The ammonia nitrogen in the water is absorbed by the nitrifying bacteria on the biofilm and converted into energy for the growth and reproduction of the microorganism, to achieve the purpose of removing the ammonia nitrogen quilt. The ammonia nitrogen transformation process in the pipeline is shown in Fig.1. The
nitrification of biofilm is affected by many factors, such as temperature, dissolved oxygen concentration, nutrient content, type, and dosage of disinfectant.

Fig.1. Nitrification of biofilm in water conveyance process

2. Influencing factors of biofilm nitrification in raw water transportation process

2.1. Temperature
The temperature in the water pipeline is a critical factor affecting the nitrification of biofilm. The optimum temperature for the growth of nitrifying bacteria is 20 ~ 30 ℃. If the temperature is lower or higher than this range, the activity of nitrifying bacteria will be affected, and nitrification will be inhibited, but not completely. Katarina [1] et al. simulated the growth of pipeline biofilm in North America. According to their research results, nitrifying bacteria can survive at 22 °C, 12 °C, and 6 °C, and there is nitrification.

2.2. Dissolved oxygen concentration
The dissolved oxygen concentration in the water in the pipeline will affect the community composition of biofilm microorganisms and change the conversion rate of ammonia nitrogen. Nitrobacteria are specialized aerobic bacteria. It is generally accepted that oxygen acts as an electron acceptor in the nitrification proceeds to convert ammonia-nitrogen and nitrite nitrogen. Feng [2] et al. used an internal circulation pipeline simulation system to explore the effect of dissolved oxygen concentration on ammonia nitrogen in effluent water and found that when dissolved oxygen concentration raised from 6 mg/L to 11 mg/L, the activity of nitrifying bacteria enhanced, and the growth rate of ammonia nitrogen concentration in effluent water dropped from 233% to 100%.

The long-distance pipeline is in a closed state, and the biofilm in the pipeline will not be exposed to the outside air, and the biofilm in the pipeline will be affected by the external air. With the extension of water delivery distance, microorganisms need to consume oxygen to degrade organic matter, which leads to the concentration of dissolved oxygen lower than that at the inlet. Therefore, the abundance of aerobic microorganisms will decline and the abundance of anaerobic microorganisms will rise along the pipeline. Z. Shen [3] et al. showed that in the early stage of water inflow, the dissolved oxygen concentration in the water body was higher, and aerobic bacteria such as Nitrospirilla and Bacteroides were the dominant species, which promoted the nitrification reaction; while when water was transported to the end of the pipeline, the dissolved oxygen concentration decreased, and the number of anaerobic genes increased, which caused Firmicutes to produce a certain denitrification effect, and the nitrifying bacteria function was inhibited.

2.3. Nutrient content
The essential nutrients for microbial growth and reproduction include carbon, nitrogen, and phosphorus sources. With different nutrient contents, the relationship between heterotrophic bacteria and nitrifying
bacteria will change accordingly, thus affecting the progress of nitrification. Liu [4] et al. found that when the C / N ratio was less than 4, the nitrifying bacteria were dominant, and when the C / N ratio was greater than 4, the nitrifying bacteria were dominant. They speculated that a high C/N ratio inhibited the ability of nitrifying bacteria to transform organic carbon and nitrous nitrogen simultaneously, leading to heterotrophic bacteria gradually occupying the dominant position and becoming dominant bacteria in the process of competition between nitrifying bacteria and nutrients.

Free ammonia also affects the nitrification of biofilms. When the content of free ammonia in water is higher, the nitrification of biofilm will be promoted. In addition, when the biofilm is impacted by disinfectant, the expansion of ammonia nitrogen concentration in water can make the nitrification recover more quickly.

Phosphorus is the main trace element that limits the growth rate and quantity of microorganisms. When the carbon and nitrogen sources are sufficient, the amount and growth rate of microorganisms on the biofilm are mainly determined by the phosphorus content in the water delivery process.

2.4. Disinfectant

To prevent excessive growth of microorganisms in the pipeline, it is necessary to add disinfectant at the water intake. However, after adding disinfectant, the stable structure of biofilm will be destroyed, which will affect the stability of water quality. When the concentration of disinfectant is low, the renewal of the biofilm microbial community will be accelerated, and the nitrification of biofilm will be promoted. If the concentration of disinfectant is too high, it will lead to the inactivation of nitrifying bacteria and the accumulation of ammonia nitrogen in the water. Wang [5] and others found that when sodium hypochlorite was added, the effluent ammonia-nitrogen concentration was 0.1mg/l, and the nitrite nitrogen concentration was 0.08mg/l; when the sodium hypochlorite concentration was 3mg/L, the number of nitrifying bacteria reduced from 400 MPN/cm² to 160 MPN/cm², and the nitrification was weakened. Therefore, the type, concentration, and duration of disinfectant should be selected according to the actual needs to ensure the effect of nitrification. The types, sterilization principles, advantages, and disadvantages of several disinfectants are shown in Table 1.

Table 1. Type, principle, advantage and disadvantage of disinfectant

| Disinfectant   | Principle                                | Advantage                                      | Disadvantage                      |
|---------------|------------------------------------------|-----------------------------------------------|----------------------------------|
| Chlorine      | Generation of hypochlorite and destruction of enzyme system in bacteria | This process has been used for a long time and it's mature; economic and effective. | Product DBPs                     |
| Sodium hypochlorite | The disinfection effect is the same as chlorine; safer. |                                               | Higher cost than chlorine         |
| Chlorine dioxide | Inactivate the protein in the bacteria | Less dosage; stronger disinfection ability than chlorine; no DBPs produced; longer retention time of residual chlorine in pipeline | Product ClO₂⁻                   |
| Chloramine    | Destroy the integrity of the membrane     | Long duration; complete inactivation effect; less disinfection by-product | Weak oxidation; increase ammonia nitrogen concentration in water |
| Ozone         | Oxidizing and decomposing enzymes in      | Powerful oxidation; will not produce           | High preparation cost; limited duration |
3. **Summary**

Due to the long-term operation of long-distance water pipeline, biofilm may grow and nitrification will occur. Nitrification cannot be completed by a single strain, but by a variety of bacteria to complete the transformation from ammonia nitrogen to nitrate nitrogen. The changes of water temperature, dissolved oxygen concentration, nutrient content, and adding strategy of disinfectant in water pipeline will affect the structure and composition of biofilm, the activity, and quantity of nitrifying bacteria, the relationship between nitrifying bacteria and heterotrophic bacteria, which will cause the change of nitrification of the biological membrane in the pipeline, and finally affect the water quality.

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