Proliferation of biomass and its impact on the operation of a submerged membrane bioreactor

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Abstract. The aim of this work was to investigate the biomass proliferation and its impact on the operation of a submerged membrane bioreactor (sMBR). A programmable logic controller (PLC) was used to control the process of the sMBR with no discharge of sludge. When MLSS was 9670 mg/L and the solid retention times (SRT) ranged from 20 to 40 days, the optimal removal efficiencies of COD, NH₃-N, TP were 93.89%, 93.02%, 80.57%, respectively. Accompanying with the decreasing of the sludge loading, the substrate and nutrition were insufficient in the sMBR, leading to endogenous respiration of the activated sludge, which decreased the activity of sludge and resulted in the death of more microorganisms.

1 Introduction

Submerged membrane bioreactor (sMBR) is a water treatment process combining high efficiency membrane separation technology with biological treatment characteristics of activated sludge. Due to the interception of the membrane, there is no need for the secondary sedimentation tank to separate solid and liquid, all the biomass can stay in the reactor and reach a high concentration, which makes the process has the advantages of a small footprint, high quality of effluent, complete solid-liquid separation and so on^[1]. In the process of operation, membrane components are prone to be polluted, resulting in a decrease in membrane flux and membrane performance, resulting in an increase in operating costs, which hinders its widespread application in practice^[2]. Study showed that the concentration of biomass is one of the important influence parameter on running the sMBR reactor ^[3], it not only affects the removal efficiency of pollutants, but also affects the viscosity^[4], extracellular polymer (EPS) content^[5] and other characteristics of sludge in sMBR. Therefore, high biomass concentration is a necessary guarantee for sMBR to achieve efficient sewage purification, but it is also a key factor to increase membrane component pollution and hinder rapid mass transfer (such as oxygen supply, nutrient transfer, and metabolite transfer), thus affecting the overall operation efficiency of the system.

Based on the conflicting effects of biomass concentrations in operating sMBR, the PLC automatic control system was used to control the process of the sMBR with no discharge of sludge, In order to investigate the law of biomass proliferation and the effect on sMBR performance at biomass breeding process, so as to provide basic basis for optimizing process operation

conditions and designing reactors rationally.

2 Results and Discussion

2.1. biomass proliferation during the sMBR operation

Due to membrane interception, large molecular biomass such as humus, glycan lipid and metabolites of other microorganisms in the system could be enriched^[6] to maintain high concentration of sludge biomass ^[7, 8]. Among them, MLSS and MLVSS were important indicators of microbial biomass in the sludge mixture, which's changes reflect the microbial proliferation in the bioreactor ^[9]. By increasing the organic load at each stage of the experiment, which promoted the proliferation of biomass in the system, and investigated the proliferation of biomass in sMBR.

This experiment was divided into three stages according to the proliferation of biomass, as shown in figure 1. From 1 to 17 days for I stage, the mixture temperature was 20~24°C, after domestication, the biomass increased gradually in sMBR, and MLSS and MLVSS stabilized at about 5g/L and 4g/L respectively; From 18 to 40 days for II stage, biomass started to increase again, but because the sludge load (F/M) and temperature (22~30.5°C) fluctuated greatly at this stage, the biomass fluctuated greatly at this stage, while MLSS and MLVSS were about 10g/L and 7g/L respectively; From 40 to 60 days for III stage, With the increase of nutrient concentration and the relatively stable state of F/M and temperature, the biomass began to grow rapidly. After the 44th day, the biomass remained relatively stable.

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Figure 1. Changes of Biomass and F/M during sMBR operationing

The test results of figure 1 showed that the start-up phase because of the low sludge concentration and high sludge load, which provided the impetus for microbial growth of II phase, the rapid microbial proliferation led to rapid increase in sludge concentration, In III phase, due to the increase of the organic load and the temperature basically around 30°C in the system and, which created an environment for the rapid growth of microorganisms and promoted the rapid growth of microorganisms; After the sludge concentration increases to a certain amount, the sludge load immediately decreased, the nutrients and energy provided by the substrate were relatively reduced, and the increase of sludge concentration slowed down. Thus, with the increase of system running time, F/M decreases relatively with the increase of biomass concentration in sMBR process.

2.2. changes of effluent water quality during operation

The change of effluent COD, $\text{NH}_3\text{-N}$ and TP in each stage was measured at the experiment with no discharge of sludge, to investigate the influence of biomass proliferation on effluent water quality and determine the optimal biomass concentration for system operation.

Figure 2 showed the changes of COD, $\text{NH}_3\text{-N}$ and TP during system operation. In I phase, At the initial stage of system operation, COD, $\text{NH}_3\text{-N}$ and TP removal was unstable, the effluent water quality exceeded the standard. Since the reactor was in the start-up stage at this time, the microbial biomass was relatively small in the system, which was not enough to fully degrade the pollutants. In addition, the membrane component was less polluted, and only a few microorganisms attached on the surface of membrane holes and filaments. The membrane component only played a filtering role. As the reaction time went on, the microbial species and quantity in the system increased gradually, the quantity of nitrifying bacteria and phosphorous accumulating bacteria increased accordingly, the removal rate of COD and $\text{NH}_3\text{-N}$ increased steadily, the removal rate of TP was improved to some extent. At this point, due to the

increase of accumulated microorganisms on the surface of membrane holes and filaments, part of COD and $\text{NH}_3\text{-N}$ in sewage during the suction process were consumed by microorganisms attached to the membrane assembly, which further reduced the concentration of effluent pollutants.

The system in the stage of II biomass proliferation, biomass average concentration was 9670 mg/L, the average concentration of COD, $\text{NH}_3\text{-N}$ and TP were 21.40 mg/L, 1.03 mg/L and 0.68 mg/L, the average removal rate reached 93.89%, 93.02% and 80.57%, respectively. Due to the increase of pollutant load, microorganisms in the system were affected by certain impacts, leading to the reduction of the initial pollutant removal rate. With the progress of the reaction, the biomass concentration of the system proliferated rapidly, which enhanced the system's impact resistance and improved the removal rate of pollutants. In general, the concentration of biomass in this stage was relatively large, the microbial species was relatively rich, the quantity was various, the system run stably and the treatment effect was good. However, due to the unstable aeration, the DO diffusion was not uniform, which led to the failure of phosphorous accumulating bacteria to absorb sufficient phosphorus in aerobic phosphorus absorption stage, the removal rate of effluent TP had certain fluctuation.

Figure 2. COD, $\text{NH}_3\text{-N}$, TP concentration variations in influent and effluent

In III phase, with the load increased, concentration of biomass in the system rose gradually, the biomass concentration gradually increased from 9670 mg/L to 15118mg/L. Pollutants removal efficiency and stability of the system decreased than II phase, average removal rate of COD, $\text{NH}_3\text{-N}$ and TP fell 2.54%, 8.62% and 43.57% respectively. The reason might be that with the increase of biomass concentration in the system, the consumption of dissolved oxygen was large, the nitrifying bacteria cannot get enough dissolved oxygen for nitrification, the microbial decomposition activity of organic matter and the nitrification rate decreased in the system, the removal of COD, $\text{NH}_3\text{-N}$ became worse. The reasons for the radical change of TP removal rate were as follows: first, the concentration of biomass was high, the intensity of aeration was insufficient, the dissolved oxygen in the system was low, then the phosphorus accumulating bacteria was inhibited to a certain extent in the stage of aerobic phosphorus absorption; Second, because the system had not discharged mud since the operation, the SRT was longer, and the TP content in the sludge was close to saturation. Therefore, Without discharging phosphorus-rich sludge, if only relying on biological phosphorus removal, the removal of phosphorus in the system could not meet the discharge requirements. In the later stage of the system, the method of combining biological phosphorus removal with chemical phosphorus removal could be adopted.

In summary, under the condition of constant operating conditions, with the proliferation of endogenous substances in the system, the sludge concentration increased from the start of the experiment to 9670mg/L, and the proliferation of biomass significantly promoted the treatment effect and stability of the system. When the biomass increased from 9670 mg/L to 15118mg/L, Due to the high concentration of biomass, low intensity of systematic aeration and low dissolved oxygen, the ability of microorganisms to degrade pollutants was inhibited to some extent. In order to ensure the strong load resistance capacity and water yield stability of the system, the biomass concentration with the best operation effect of the system was 9670mg/L.

2.3. influence of biomass proliferation on sludge activity

Dehydrogenase activity reflects sludge activity by measuring dehydrogenation and hydrogen rate of microorganisms in the process of degrading organic substances. Dehydrogenase is produced by living organisms, and the enzyme can promote the dehydrogenation of organic substances, which can reflect the active microbial biomass and its degradation activity to organic substances in the biological treatment of wastewater [10]. With the gradual decrease of F/M, the influence of biomass proliferation on sludge activity was investigated.

In the process of this experiment, with the increase of running time and the proliferation of biomass, the changes of sludge sedimentation and activity was shown

in figure 3. In I phase, The biomass was stable and not large, F/M was relatively high, and the dehydrogenase activity of sludge first decreased and then increased rapidly; In II phase, as biomass proliferation, the activity of sludge in system further increased, rapidly declined in late, and continued until the III phase; In III stage, although the activity of sludge increased in small stages, it decreased gradually.

Figure 3. Variations of Sludge Activity in process

According to the analysis, the microbial living environment in sMBR was much worse than other biological treatment processes, the main performance was the strong shear force produced by aeration and the long age of sludge. Strong shear force was easy to break the bacteria micelle, not conducive to the growth of bacteria; However, the longer sludge age led to the increase of sludge concentration, load reduction and the accumulation of a large number of inert substances and microbial metabolites in the mixture. Meanwhile, the sludge was in the endogenous respiration stage and the number of dead bacteria increases, which inevitably led to the decline of system sludge activity.

3 conclusion

The biomass concentration with the best operation effect of the system was 9670mg/L, and the removal rates of COD, $\text{NH}_3\text{-N}$ and TP were 93.89%, 93.02% and 80.57%, respectively. Before the concentration of biomass increased to 9670mg/L, biomass proliferation significantly promoted the processing effect and stability of the system.

The system did not discharge sludge for a long time, with the decrease of F/M, the substrate and nutrients of microorganisms were insufficient, under the action of endogenous respiration, the sludge activity in sMBR decreased and the number of dead microorganisms increased.

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