Practical research on the modular equipment for the treatment of rural decentralized domestic sewage

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Abstract—The research and application of the modular equipment for decentralized domestic sewage treatment based on the technologies of anaerobic-anoxic-aerobic and membrane bioreactor methods are carried out and the result shows that the technical and economic indexes at each stage of the study all meet and exceed the first class A emission standard of urban sewage treatment pollutant emission standard(GB18918-2002). The concept of decentralized treatment offers great potential for developing sustainable environmental protection and energy conservation, decentralized sewage control and management will result in significant savings in capital and operating costs for drainage networks and pumping stations especially in water-scarce areas. Decentralized wastewater treatment should be regarded as an important concept of municipal wastewater treatment and a feasible treatment program. Decentralized wastewater treatment technology has a broad development prospect in the future wastewater treatment field.

1. Introduction
The problem of water resources is the key factor that restricts the development of social economy. Traditional centralized processing technology is difficult to fully apply in villages, towns and residential areas because most of these areas do not have a sound pipe network system, but also can not afford the high cost of laying. On the other hand, the amount of sewage in these areas is relatively small and fluctuates greatly. Compared with municipal sewage, the concentration of decentralized domestic sewage pollutants is relatively low. It belongs to medium-low concentration domestic sewage and has generally good biochemical properties, so it is economical to use and simple maintenance. Domestic sewage decentralized treatment technology, that is, the domestic sewage produced in areas without centralized sewage treatment will be treated to meet the standards of discharge or reuse. Utilization of different sewage treatment technologies according to local natural conditions can reduce water pollution and save water resources [1]. Decentralized wastewater treatment technologies aim to minimize the use of freshwater resources, reduce the amount of transboundary pollutants and ultimately maximize the reuse of water[2]. It has many advantages such as low operation cost, good treatment effect, flexible process operation, no residue and is widely and deeply studied and widely adopted. The performance of modular wastewater treatment equipment for small-scale wastewater treatment mainly focusing on the small-scale anaerobic-anoxic-aerobic(A2O) process (treatment capacity less than 100 tons per day) have been researched currently, however, there are few reports on the large scale decentralized wastewater treatment equipment. For this reason, based on the actual water quality in sewage treatment, the degradation of domestic sewage pollutants in an A2O+ membrane bioreactor(MBR) process under different conditions was studied by pilot-scale
test in this paper and provided reliable theoretical basis for the sewage treatment system to reach the standard and save energy consumption.

2. Related work

Domestic sewage decentralized treatment technology is developed on the basis of traditional sewage treatment technology which can be divided into good anaerobic biological treatment technology and natural biological treatment technology. Currently, in order to complement the advantages of a number of single processes, it is a trend to couple wastewater treatment processes including membrane bioreactor, microbial fuel cell and septic tank reactor and the combination of biological methods with electrochemical systems has proved to be most useful. Artificial wetlands are constructed and controlled by humans to operate on land similar to marshland, utilizing the triple coordination of physical, chemical and biological functions of the ecosystem through filtration and adsorption, ion exchange precipitation, plant absorption and decomposition for microorganisms to achieve the efficient purification of water domestic sewage. Wu et al [3] compared the removal efficiency of organic pollutants and nitrogen in vertical flow constructed wetlands (VFCWs) with intermittent aeration and different influent intensities and supplied a possible method for the treatment of decentralized wastewater in north China. Zhou et al [4] investigated the effect of nitrogen and phosphorus removal in domestic wastewater by integrated MBR process, the results show that under the condition of the dissolved oxygen(DO) concentration is 0.10~0.30mg/L, the average removal efficiencies of chemical oxygen demand(COD), NH$_3$-N and total phosphorus (TP) were 88.90%, 94.60% and 61.60%. Zhang et al [5] designed a two-stage biological fluidized bed (MBBR) to research chemical phosphorus removal process for the treatment of campus dispersed domestic wastewater and the result of operation show that the effluent finally could reach the first grade discharge standard of GB 8978-1996 wastewater comprehensive discharge standard. MBR is a new wastewater treatment technology which combines biological treatment unit and membrane separation unit. The secondary sedimentation tank is replaced by membrane module to reduce the area of the treatment facilities and to reduce the sludge quantity by keeping the sludge load low. The activated sludge concentration in the membrane bioreactor can reach 8000~10000mg/L, the sludge age can reach more than 30 days, MBR is the retention of macromolecule organic matter and activated sludge in the tank by using membrane separation equipment, MBR has the retention effect, the long-term microorganisms such as nitrifying bacteria can be retained to make the system have better nitrification effect and provide the possibility for deep nitrogen and phosphorus removal. The MBR process has the advantages of high impact load resistance, good treatment effect, stable effluent water quality, easy operation and management, less excess sludge and small occupied space. Nowadays, the MBR process is widely used in the field of wastewater treatment especially in the field of decentralized wastewater treatment and reuse because of the increase of membrane flux, the decrease of membrane cost and the extension of membrane life. The removal efficiency of nitrogen and phosphorus is low in the independent MBR process, so MBR is usually combined with other processes such as submerged composite bioreactor, cyclic alternating activated sludge bioreactor, biological moving bed bioreactor, submerged bioreactor, cyclic intermittent activated sludge bioreactor, anaerobic+aerobic+anoxic sequencing batch bioreactor [6-10]. These new processes enhance the treatment effect, the removal rate of nitrogen and phosphorus is increased and the membrane fouling is reduced. In other areas of research, the quality of effluent is poor due to the limited biomass retention capacity of microbial fuel cell(MFC). Wang et al[11] designed an integrated MFC-MBR system, in which the aeration tank of MBR was directly used as the cathode chamber, the carbon felt was used as the cathode for the development of biofilm and the low-cost Nylon net was used as the filter material[12]. The results show that the removal rate of COD is (89.6±3.7)% and the concentration of suspended solids (SS) is almost zero. Zhou et al[13] developed a new type of overflow electrochemical membrane bioreactor for wastewater treatment and utilized the electric energy recovered from microbial fuel cell to alleviate membrane fouling in membrane bioreactor. The removal efficiencies of COD, NH$_3$-N and TN were (92.6±5.4)%, (96.5±2.8)% and (73.9±9.7)% respectively. The principle of A$^2$O system is to remove
pollutants from sewage through the metabolic activity of microorganisms in activated sludge[14]. The A²O wastewater treatment process mainly uses the nitrification reaction of aerobic tank and the denitrification of anoxic tank to remove nitrogen and uses the phosphorus release of anaerobic tank and the phosphorus uptake of aerobic tank to remove phosphorus. The process is characterized by simple running process, low cost and simultaneous removal of nitrogen and phosphorus[15-16].

3. Materials and methods

3.1. Wastewater

The decentralized domestic sewage of the research project is taken from Julong town, Pengan County, Nanchong City, Sichuan Province and the sewage volume is about 700~800 tons per day. The characteristics of domestic sewage in this area are similar to that of common domestic sewage including bath sewage, toilet sewage, kitchen sewage and sewage from small-scale catering service industry. The water quantity and water quality fluctuates greatly, the water basically do not contain heavy metal and the poisonous harmful substance, the nitrogen, the phosphorus content is higher. The quality parameters of domestic sewage are as follows in Table 1. The wastewater treated by the modular treatment equipment can meet the first class A emission standard of urban sewage treatment pollutant emission standard(GB 18918-2002). The quality of the outgoing water is shown in Table 2. After the wastewater is treated by the sewage treatment station, it is discharged into the nearby Jialing river finally.

| test item  | pH  | COD     | BOD₅  | NH₃-N | TP     | fecal coligroup count |
|------------|-----|---------|-------|-------|--------|-----------------------|
| value      | 6~9 | 240.0~780.0 | 110.0~360.0 | 9.0~23.0 | 5.0~12.0 | 1.0×10¹¹~1.6×10¹¹ |
| unit       | mg/L| mg/L    | mg/L  | mg/L  | MPN/L  |

Table 2. The discharge standard of domestic sewage

| test item  | pH  | COD | BOD₅ | NH₃-N | TP | fecal coligroup count |
|------------|-----|-----|------|-------|----|-----------------------|
| value      | 6~9 | 50.0| 10.0 | 5     | 0.5| 1000                  |
| unit       | mg/L| mg/L| mg/L | mg/L  | MPN/L|

Through the analysis of the above water quality, it can be seen that the domestic sewage in the area has good biodegradability, high NH₃-N, total phosphorus and moderate pH value, so it is feasible to treat the sewage by biological method with the function of nitrogen and phosphorus removal.
3.2. Methodology and experimental procedure

The decentralized sewage treatment process flow diagram are shown as Figure 1. The process consists of anaerobic reactor, anoxic reactor, aerobic reactor and MBR tank. The final wastewater is discharged after being treated by an ultraviolet on-line sterilizing equipment. Under the condition that the volume of the wastewater treatment reactor is certain, the control of the hydraulic retention time (HRT) is adjusted by the inflow of water. HRT is one of the most important design parameters in the wastewater treatment process and the size of it directly represents the length of time the wastewater stays in the reaction tank and the volume of the reaction tank. The time the wastewater stays in the reaction tank will directly affect the treatment effect of the process and the size of the tank capacity is related to the project cost and area. This study mainly focuses on analyzing the effect of hydraulic retention time (HRT) on COD and other indicators.

3.3. Materials and Analytical methods

The membrane of MBR is Polyvinylidene Fluoride (PVDF) hollow fiber membrane which has been produced by Shandong Zhaojin Motian Co., Ltd. The effective area of the membrane is 2500M², the height is 3150mm, the pore diameter of membrane closure is 0.05μm and the flow rate of water production is 500~600M³/d. COD, BOD₅, SS were determined by multi-parameter water quality tester 5B-3B(V11) produced by Beijing Lianhua YongXing science and technology development Co., Ltd. The pH measurement was performed using a laboratory table-top pH meter (Model PHS-3, Shanghai Leici instrument Co., Ltd. China). The water quality indexes of sewage such as COD, NH₃-N, TN, TP were analyzed by national standard method [17].

4. Results and discussion

4.1. Optimization analysis of A²O process parameters and operation conditions

A²O process is the simplest process for simultaneous nitrogen and phosphorus removal. It has good purification capacity for domestic sewage. Because of using the state of complete mixing of sludge in traditional activated sludge, sludge bulking is easy to occur, which directly leads to the reduction of wastewater purification capacity and the poor quality of effluent water. The traditional A²O process was improved by using biological contact oxidation method in A²O activated sludge. A packing was placed in the contact oxidation tank, and the packing was submerged in the sewage, and the packing was covered with biofilm, the organic matter in water is adsorbed, oxidized, decomposed and transformed into a new biofilm by microorganism. Because of the high specific surface area of the filler and the good oxygen-filling condition in the pool, the bio-solid content per unit volume is higher than that of the traditional activated sludge and has a higher volume load. At the same time, the bio-contact oxidation method does not need the backflow of sludge and does not have the problem of sludge bulking. The secondary sedimentation tank which has the functions of solid-liquid separation and sludge concentration, needs to be set up in the traditional activated sludge. In order to obtain strong adhesion of biofilm, composite packing was used. With the development of biofilm-forming process, a small amount of gray fluff-like biofilm gradually appeared on the surface of the packing. The longer hydraulic retention time and the lower hydraulic load were beneficial to the adhesion and growth of the sludge on the surface of the packing. With the extension of the film-forming time, the microorganisms attached to the surface of the packing get a lot of reproduction, the color gradually from mud yellow to yellow brown, then to gray brown. At the same time, with the increase of the flow rate of the system, the removal rate of COD did not decrease, but remained at a higher level and finally reached 95% removal rate, at which point the concentration of COD in the system effluent was 15 mg/L. The results show that the system is basically successful.
4.2. Study on the influence of hydraulic retention time (HRT) on the system

In the course of the experiment, the HRT was changed to 9h, 7h, 5h, 3h, 1h and 0.5h by controlling the water flow rate of the system. The system was run for 3 days under different HRT and the average value of 3 days was taken as the data analysis. After changing the hydraulic retention time, at least one day after the stabilization, the data were tested again. The operating parameters of the system are as follows: aeration rate is 0.18 M³/h, air-water ratio is 30:1. With the increase of HRT, the removal efficiency of COD is better. The removal rate of COD increased from 79.73% (HRT=0.5) to 98.43% (HRT=9) and the COD concentration of effluent decreased from 252.0 mg/L to 12.2 mg/L. According to the above data, the removal rate of COD is stable when the HRT is more than 3h, and the COD concentration of effluent is below 14mg/L. It can be seen that the hydraulic retention time of the system is about 3~5h, which can meet the requirement of decarbonization of the system. The main reason for this change is that the degradation of organic matters is mainly accomplished by the adsorption and degradation of biofilm, and the contact time between organic matters and biofilm is short and partial under the condition of lower HRT, organic matter has not been degraded with water, so the longer HRT is beneficial to the complete degradation of organic matter.

5. Conclusions

In this paper, the concept of decentralized sewage treatment is expounded and the decentralized sewage treatment technology has been studied, anaerobic-anoxic-aerobic and membrane bioactor methods are adopted to study decentralized sewage in rural regions in China. Optimization parameters of anaerobic-anoxic-aerobic process parameters and operation conditions and the effect of hydraulic retention time on the main water pollution factors are investigated and the technical and economic indexes at each stage of the study all meet and exceed the first class A emission standard of urban sewage treatment pollutant emission standard(GB18918-2002). In terms of the future work, the improvement of membrane performance and further optimization of parameters should be carried out to enhance practicability of treatment process.

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