Pilot Scale Study on Combined Ultra Filtration and Other Technique to Treat Rural Domestic Sewage

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Abstract. The rural domestic sewage was treated by using combined ultra filtration with reverse osmosis (RO), constructed wetlands and biofilter respectively. The results showed that the average concentrations of COD, TP, NH$_4$-N and TN in the effluent were 118.1, 5.4, 75.5 and 85.0 mg/L, and the average removal rates were 77.0%, 58.1%, -2.7%, and 15.1% by ultra filtration respectively. And then the effluent treated by RO process, the above water quality indicators had reached the I A level of the discharge standard of pollutants for urban wastewater (GB18918-2002). The average removal rates of COD were 35.6% and 35.1%, TP were 11.9% and 9.8%, NH$_4$-N were 5.4% and 23.7%, and TN were 6.1% and 7.6% by constructed wetlands and biofilter respectively. The overall removal rates of pollutants were not high and the effluent quality was not stable through the above two techniques. Therefore, further improvement is needed in design and operation of constructed wetlands and biofilter. Ultra filtration-reverse osmosis integrated equipment can be designed to treat dispersed domestic sewage in rural areas.

1. Introduction

9 billion tons of rural sewage are discharged in China each year, about 80% of these being discharged directly into natural river or lake without any treatment. This is one of the important factors leading to the decline of rural water quality in China[1-2]. The Taihu lake region is one of China's developed and populated areas. The governments have built lots of small domestic sewage treatment stations in many villages of the area to control water pollution since blue-green algal bloomed in 2007. Most of these domestic sewage stations use improved SBR(Sequencing Batch Reactor Activated Sludge Process), MBR(Membrane Bio-reactor), biological contact oxidation, and other treatment processes, which have a certain effect on improving the water quality of the Taihu Lake area. However, the scale of rural sewage treatment is small and distributed widely, and the construction and operation costs is relatively high. There are great difficulties in continuous operation[3-4]. Therefore, it is urgent to explore and study the technological process of rural domestic sewage treatment and reduce its operation and maintenance cost.

Ultra filtration and RO both use membrane separation to filter and remove pollutants in water. In recent years, with the improvement of membrane performance and the decrease of price, ultra filtration plays an increasingly important role in domestic sewage treatment. The pore diameter of RO membrane is generally between 0.1nm and 1nm, and it has a high removal rate for most inorganic salts, dissolved organics and colloid[5-6]. Constructed wetland is an engineered wetland and plant is an important part of the treatment system, which has higher productivity and pollutant removal rate than natural wetland. The biological filter relies on the metabolic activity of the biofilm attached to the
surface of the filler to degrade the pollutants and has a good removal effect on the pollutants in the water [7-8].

The pilot study was conducted to provide technical and practical support for the treatment of rural domestic sewage in Dagang village in the Taihu lake region, using ultra filtration with the above three treatment technologies.

2. Technological Process and experiments

The pilot scale study was conducted in two stages. The pilot test of the ultra filtration-reverse osmosis process was carried out in the first stage, which lasted for 20 days, and water samples were taken every 3 to 4 days. In the second stage, ultra filtration-constructed wetland system and ultra filtration-biological filter were conducted, which lasted for 4 months, and water samples were taken every 3 to 4 days too. The COD, TP, TN and NH₄-N in the samples were measured according to potassium dichromate method (HJ828-2017), ammonium molybdate spectrophotometry (GB/T11893-1989), alkaline potassium persulfate digestion-UV spectrophotometric method (HJ636-2012) and Salicylic acid spectrophotometry respectively (HJ536-2009) respectively.

3. Results and discussion

3.1. Removal effect of several processes on COD

Figure 1 shows the removal effect of COD in rural domestic sewage by four treatment technical. The COD of the domestic sewage were 11.5mg/L-2096.0 mg/L with a large variation range. After the ultra filtration treatment, the COD dropped to 7.4mg/L-304.7mg/L, the average being 118.1mg/L, and the average removal rate was 77.0%. The ultra filtration membrane could filter suspended matter and particulate matter in sewage. The average water output in the study was 5.7m³/h. The mud was discharged once every 3 days, and the equipment ran stably.

![Figure 1. COD removal result by treatment systems.](image)

In the first stage of the study, the sewage water entered into the RO equipment after ultra filtration treatment. The removal rate of colloids and dissolved organic matter was high because of the nano membrane filter. After the RO process, the COD of the effluent dropped to 15.0-49.0mg/L, which was lower than the requirement of 50mg/L in the I A level of the discharge standard of pollutants. During the operation of the RO system, the RO membrane were contaminated due to the interception of pollutants, resulting in an increase in operating pressure and a decrease in the water production rate. And then regular washing of membrane were required in order to ensure the continuous operation.

In the second stage of the study, the ultra filtration water flowed into the constructed wetland and the biological filter respectively. After passing through the constructed wetland system, the average COD concentration decreased from 116.6 mg/L to 75.1mg/L, and the average removal rate was 35.6%. Most of the time, the wetland system had a high removal rate of COD, especially when the influent COD was about 200 mg/L, the removal rate can reach 60%-80%. In addition, the first-stage aeration of the wetland can create a good aerobic environment, so that organic pollutants were degraded by...
aerobic microorganisms. And then most of them could be removed by continuous sedimentation, filtration, and biofilm adsorption and biological metabolism of plant roots\cite{9,10}. However, the removal of COD by the wetland system was unstable because the particulates and colloids intercepted by the constructed wetland matrix would be discharged with the water flow, and affected the quality of the effluent water.

By the biological treatment, the average COD of the effluent water decreased from 131.9mg/L to 85.5mg/L, the removal rate was between 1.8% and 59.2%, the average removal rate being 35.1%. During the operation of the biological filter, the anaerobic section often needed aeration to flush the pollutants trapped in the packing layer, which made the effluent water quality fluctuate greatly.

3.2. Removal effect of several processes on TP
In the operation of the ultra filtration process, the addition of PAC is the key factor. Soluble phosphates in sewage could be mixed with PAC to form particulate matter, which was trapped in the membrane tank through chemical precipitation and flocculation reactions\cite{5}. The effect of ultra filtration on TP removal is shown in Figure 2. It could be seen from Figure 2(a) that the TP in the sewage was 0.6-31.0mg/L. After ultra filtration, the TP in the effluent was greatly reduced within the range of 0.3 to 13.9 mg/L, and the removal rate was 18.5%-96.2% with large fluctuations. The effect of chemical precipitation on phosphorus removal was affected by factors such as pH, agitation time, and the amount of agent added. The TP in the waste water fluctuated greatly, but the dosage of PAC did not change at the same time. As a result, it leaded to a phenomenon of insufficient dosage of chemicals, which affected the phosphorus removal effect.

![Figure 2. TP removal result by treatment systems.](image)

The effluent flowed into the RO system after the ultra filtration treatment. The TP concentration in the effluent was 0.5-0.9mg/L by the RO membrane treatment because of its good retention effect on inorganic salts.

The effluent flowed into the constructed wetland after the ultra filtration treatment. By constructed wetland treatment, the average concentration of TP in the effluent decreased from 5.9mg/L to 5.2mg/L, and the average removal rate was only 11.9%. The treatment effect did not meet the predetermined requirements, and the TP concentration of the constructed wetlands even exceeded the inflow concentration in some times. Phosphorus removal in constructed wetlands were due to plant absorption, microbial assimilation, and filtration and adsorption of fillers. Among them, the filtration and adsorption removal of fillers was the main factor. The matrix can absorb a large amount of phosphorus in the wetland at the initial stage of treatment. The matrix adsorption became saturated and even the desorption phenomenon appeared with time, which made the phosphorus removal effect showed a certain fluctuation\cite{11,12}. In addition, the study period was in autumn and winter, and the reeds planted in the system were not growing well, some even withered, and their phosphorus utilization capacity was limited.

The effluent flowed into the biological filter after the ultra filtration treatment. By the biological filter, the average TP concentration dropped from 7.3mg/L to 6.6mg/L, with an average removal rate
of 9.8%. The TP concentration in the effluent increased in some times. Biological filter could remove phosphorus mainly by assimilation of microorganisms and filtration and retention of filler. So the phosphorus-containing pollutants accumulated in the filter material and at the bottom would be washed into the water layer, causing the TP concentration fluctuate in the effluent.

3.3. Removal effects of several processes on NH\textsubscript{4}N

Figure 3 shows the removal of NH\textsubscript{4}N by several processes. It could be seen from Figure 3(a) that during the operation of the ultra filtration process, the NH\textsubscript{4}N concentration in the inlet water was 3.6-172.1 mg/L, the effluent concentration was 1.5-180.2 mg/L, the removal rate was -29.4%-58.1%. The removal effect of this method was very unstable because NH\textsubscript{4}N was a small inorganic molecule, and then it could penetrate through the ultra filtration membrane. On the other hand, because the sludge was discharged for 3 days, the concentration of residual NH\textsubscript{4}N in the membrane pool was high, which could pass through the ultra filtration membrane with the water.

![Figure 3. NH4-N removal result by treatment systems](image)

By the RO treatment after the ultra filtration process, the concentration of NH\textsubscript{4}N was between 3.75 and 4.56 mg/L, and the removal rate was about 90%, which is lower than the requirement of 5 mg/L of standard A of sewage discharge level I.

By the constructed wetland treatment after the ultra filtration process, the average NH\textsubscript{4}N concentration decreased from 85.2 mg/L to 80.6 mg/L, with an average removal rate of 5.4% and a maximum removal rate of 90.9%. The removal effect was very unstable. Nitrification and plant root absorption were the main ways to remove NH\textsubscript{4}N in constructed wetland. The wetland could form a micro-aerobic environment in the wetland by means of water carrying oxygen, atmospheric reoxygenation, and plant root oxygen transport. In these micro-regions, NH\textsubscript{4}N was converted into nitrate nitrogen, and made NH\textsubscript{4}N concentration reduce. In subsurface flow constructed wetland, plant root oxygen transport capacity and water reoxygenation capacity were limited, so they were mostly anaerobic with poor nitrification and low NH\textsubscript{4}N removal rate\textsuperscript{[13-14]}.

By the biological filter treatment after the ultra filtration process, the average NH\textsubscript{4}N concentration decreased from 93.0 mg/L to 78.5 mg/L, the average removal rate was 23.7%, and the removal rate was -17.3%-94.5%. In the biological filter, NH\textsubscript{4}N could be transformed into nitrate and nitrite in the aerobic zone through nitrification and nitrosation. However, COD fluctuated greatly in the water, and nitrification and nitrosation bacteria were very sensitive to COD of the water, resulting in unstable nitrification, and leading to unstable removal rate of NH\textsubscript{4}N in the effluent\textsuperscript{[15]}.

3.4. Removal effects of several processes on TN

The removal of TN by several processes is shown in figure 4. During the operation of the ultra filtration process, the TN concentration in the influent was between 9.6 mg/L and 218.9 mg/L, the effluent concentration was between 4.0 mg/L and 181.7 mg/L, the average concentration had dropped from 100.1 mg/L to 85.0 mg/L, the average removal rate was 15.1%, and the removal rate was between -29.4% and 58.1%. The TN removal effect was unstable, and some effluent concentrations also
appeared to rise. There was a phenomenon that the concentration of TN and NH₄-N increased in the same time, indicating that the ultra filtration had a good interception effect on nitrogen-containing organics of macromolecules. However, due to the influence of NH₄-N permeation in the membrane pool, the TN removal rate was not high.

By RO treatment after the ultra filtration process, the TN concentration was 4.25-5.75mg/L, and the removal rate was about 90%, which was lower than the requirement of 15mg/L in the I A level of the discharge standard of pollutants.

By constructed wetland treatment after the ultra filtration process, the average TN concentration in the effluent decreased from 94.7mg/L to 88.9mg/L, the average removal rate was 6.1%, and the removal rate fluctuated between -46.3% and 70.6%. The TN removal effect was very unstable, and the TN concentration in some effluents even rose. The time of occurrence was basically the same as the time of TP and NH₄-N in the effluent. It was also caused by the release of matrix layer and the weak absorption and utilization capacity of plant roots.

By the biological filter treatment after the ultra filtration process, the average TN concentration decreased from 103.3mg/L to 96.6mg/L, the average removal rate was 7.6%. In the composition of TN in the waste water, NH₄-N was the main component, and nitrate nitrogen concentration was not high. The biological filter treatment included both aerobic and anaerobic stage to ensure nitrification and denitrification, but the process did not work, resulting in low removal rate of TN.

4. Conclusion
The pilot study of ultra filtration combined with reverse osmosis, constructed wetlands, and biological filters respectively for rural domestic sewage treatment was conducted. After the domestic sewage was treated by ultra filtration, the average concentrations of effluent COD, TP, NH₄-N, and TN were 118.1, 5.4, 75.5, and 85.0 mg/L, and the average removal rates were 77.0%, 58.1%, -2.7% and 15.1% respectively. After further treatment with the reverse osmosis process, the concentrations of COD, TP, NH₄-N and TN in the effluent all reached the I A level of the discharge standard of pollutants for urban wastewater (GB18918-2002), and met the requirements for the discharge of major water pollutants from urban sewage treatment plants in Taihu Lake region. However, The removal effect of COD and nutrient in the effluent by ultra filtration combined with other two treatment methods were not good.

Ultra filtration-reverse osmosis can be designed as an integrated device, which has the advantages of less space, high degree of integration, and high treatment effect. It also has good ability to treat scattered domestic sewage. Constructed wetlands is economical and simple to operate, but the removal effect is unstable, and further improvements is needed in terms of filter material materials, structure, and selection of aquatic plants. The operation and maintenance of the biological filter is simple, but the removal of pollutants is very unstable, and it does not achieve the intended purpose. Further improvements will be made in terms of filler, carbon source, hydraulic retention time, and water-air ratio.
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