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The application of A/O-MBR system for domestic wastewater treatment in Hanoi

Ứng dụng công nghệ A/O kết hợp màng vi lọc để xử lý nước thải sinh hoạt ở Hà Nội

Research Article

Tran, Thi Viet Nga*; Tran, Hoai Son

Institute for Environmental Science and Engineering, National University of Civil Engineering, 55 Giai Phong Road, Hanoi, Vietnam

The study aims to investigate an appropriate wastewater treatment process to treat domestic wastewater in Hanoi City which contain low-strength for COD (120-200 mg/L) but high in nitrogen content (10-40 mg/L). A lab scale anoxic-oxic system with a hollow fiber-Membrane Separation Bioreactor was operated at a flow rate of 5-10 L/h over a period of 150 days. The reactor was operated at different sludge recirculation rates. The MBR maintained relatively constant trans-membrane pressure. During 150 days of reactor operation, treated water quality have COD of around 20 mg/L, NH_4-N of less than 1 mg/L, NO_3-N of less than 5 mg/L. The system shows good and stable efficiency for organic matter and nitrogen removal without adding an external carbon source and coagulants. The results based on the study indicated that the proposed process configuration has potential to treat the low-strength wastewater in Hanoi.

Mục tiêu của nghiên cứu là đề xuất được một công nghệ hiệu quả và phù hợp để xử lý nước thải sinh hoạt ở các đô thị của Việt nam, là loại nước thải được thu gom từ hệ thống thoát nước chung có nồng độ chất hữu cơ thấp (COD 120-200 mg/l) nhưng hàm lượng chất dinh dưỡng như Nitơ, Phốt pho khá cao (T-N: 10-40 mg/L). Chúng tôi đã nghiên cứu và vận hành chạy thử mô hình xử lý sinh học yếm khí - kỵ khí (AO) kết hợp với màng vi lọc ở quy mô mô hình phòng thí nghiệm (công suất 5-10 L/h) ở các chế độ công suất bùn tuần hoàn khác nhau. Kết quả xử lý trong thời gian 5 tháng vận hành mô hình cho thấy chất lượng nước thải sau xử lý có hàm lượng COD nhỏ hơn 20 mg/L, NH_4-N nhỏ hơn 1 mg/L, NO_3-N nhỏ hơn 5 mg/L. Hiệu suất xử lý chất hữu cơ và chất dinh dưỡng rất ổn định và hệ thống không phải sử dụng các nguồn bổ sung chất hữu cơ hay các hóa chất trợ lắng như các công nghệ đang áp dụng. Kết quả cho thấy công nghệ AO kết hợp màng vi lọc có khả năng áp dụng thực tế, phù hợp với những nơi có quỹ đất nhỏ, chất lượng nước sau xử lý rất cao có thể phục vụ cho mục đích tái sử dụng.

Keywords: wastewater treatment, MBR, nirogen removal, combined sewer system, Hanoi

1. Introduction

The urban population growth is accompanied by an increase in resources' consumption and environmental degradation. In the last decade, the pollution has worsened because the urban environmental sanitation infrastructure unfortunately is seemingly incapable of meeting the demand for appropriate services like sanitary management and wastewater treatment. It is estimated that by 2009 Hanoi discharged about 750,000 m^3 of domestic wastewater into its sewerage and drainage system every day, and only 10 percent of this amount is treated before being disposed (Vietnam Pollution Control Department, 2010). Domestic wastewater first goes into a septic tank at household then is discharged into combined sewer systems that also transport various kinds of wastewater, including storm water. A lot of efforts have been focused to identify the appropriate technology for treating this low-strength wastewater to meet the strict Vietnamese standard for wastewater discharge (QCVN 14/2008-BTNMT).

Membrane bioreactors (MBR) represent a very promising technology for wastewater treatment (Stephenson et al, 2001). In MBR, the conventional sedimentation tanks for the separation of purified water and biomass are replaced

* Corresponding author
E-mail: nga.tran.vn@gmail.com

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by a submerged membrane filtration system. MBR offers a number of advantages, including highly reliable operation independent of the hydraulic load, high effluent quality, reduced space requirements, and process intensification through higher biomass concentrations. The main limitation for the widespread application of MBRs lies in membrane fouling which reduces the filtration performance and thus increases the investment and operating costs. The MBR main power requirement comes from aeration, which is used for the supply of dissolved oxygen and to maintain the solids in suspension. The aeration in MBRs is generally provided by fine bubble aerators that keep the tank well mixed and provide oxygen to the biomass. In addition, in submerged MBRs, coarse bubble aerators situated under the membrane modules are used to scour and/or gently agitate the membranes in order to control membrane fouling (Stephenson et al. 2000).

The aim of the present study was to investigate the feasibility of treating low-strength domestic wastewater in Hanoi with COD removal and nitrification by membrane bioreactor. The second purpose of this work is to investigate the optimum operation parameters while minimizing the backwashing or chemical cleaning of the membrane modules.

2. Wastewater situation in Hanoi

Hanoi's sewerage network is a combined system in charge of collection of industrial and domestic wastewaters as well as the management of storm water and surface water run-off. Most urban residents of Hanoi have a flush toilet with a connection to the septic tank from which the effluent (septic) is discharged into sewer lines and semi-open drainage canals (To Lich river, Kim Nguu river and Set River) before flow into the Red River. Wastewater quality and quantity are therefore seasonal fluctuated as impact from the storm water.

Table 1. Domestic wastewater characteristics

Water parameters	Range	Average
BOD_5 (mg/L)	50 - 150	100
COD (mg/L)	120 - 250	200
TSS (mg/L)	30 - 120	50
NH_4-N (mg N/L)	4 - 25	15
TKN (mg N/L)	5 - 40	20
T-P (mg/L)	2 - 10	4
Fat and Grease (mg/L)	<30	-
Alkalinity (mg $CaCO_3$/L)	>100	-
pH	6-9	-

There are three wastewater treatment plants (WWTPs) with a total capacity of 48,200 m^3/day in total. These facilities were constructed by the Hanoi Drainage Project for Environmental Improvement under Japanese ODA in 1997-2005. The wastewater treatment process is the carrier-added activated sludge process with anaerobic-anoxic-oxic (A2O) process. The treated water is being discharged into open canals within the city.

Table 2: Performance of WWTP in Hanoi

	Water parameters	Raw wastewater (design value) (mg/L)	WWTP effluent* (mg/L)	Vietnamese wastewater discharge standard (QCVN 14/2008- BTNMT) (mg/L)
2	COD	225	22	-
3	BOD	150	11	30
4	TSS	180	1.6	50
5	T-N	40	16	5 (as NH_4-N)
8	T-P	5	1.4	6 (as PO_4-P)

**Note: the data for Kim Liem WWTP (source: JICA, 2010)*

An assessment of WWTP performance conducted by a JICA team (JICA, 2010) indicated that the raw wastewater mainly originates from domestic activities and contains very little industrial wastes. Therefore, organic matter is easily biodegradable. The current WWPT shows good removal efficiency in term of COD and BOD, however, low concentration of organic matter may not be sufficient to remove nutrients. When rainwater is mixed into the sewage, efficiency of the biological treatment process of the sewage, especially phosphorus removal, is reduced. External carbon sources have been used periodically for meeting the wastewater discharge standard (QCVN 14/2008- BTNMT) for nitrogen and phosphorus. All three plants have a bulky sludge problem and polyaluminium chloride (PAC) has been used as coagulant for enhancing of the settling process.

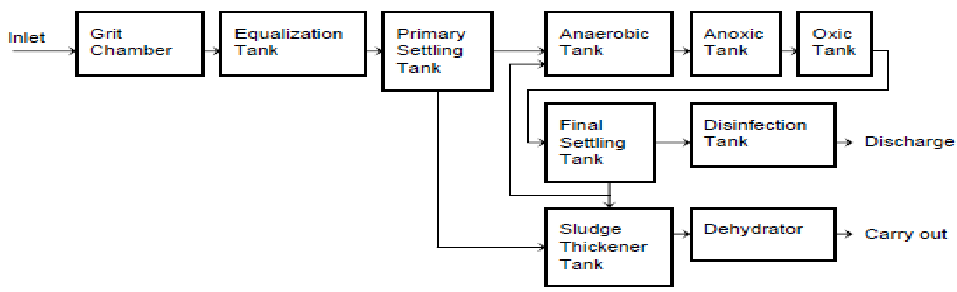

Figure 1. Diagram of current wastewater treatment processes in Hanoi City (Kim Lien and Truc Bach WWTP)

3. Materials and methods

3.1 A/O-MBR

Figure 2 shows the schematic diagram of the A/O- MBR reactor. The reactor is placed at the Kim Lien WWTP and receives feed water from the primary sedimentation tank of the plant.

The system consists of two tanks in series: anoxic tank (working volume of 20 L) and aerobic tank (working volume of 25 L). To provide adequate solid-liquid separation, a microfiltration membrane was installed in the aeration tank. A hollow-fiber, polyvinylidene fluoride (PVDF) membrane module manufactured by Motimo Co. (China). It had a surface area of $1m^2$ and a nominal pore size of 0.4µm.

The A/O-MBR system has been operated for 150 days at different hydraulic retention times and sludge recirculation rates, which were changed several times over the period of study. The average hydraulic retention times for the entire system (anoxic and aerobic tanks) were ranging from approximately 4.5 hours to about 9.0 hours in total. The sludge retention time was 60 days. The operating conditions are summarized in **Table 3**.

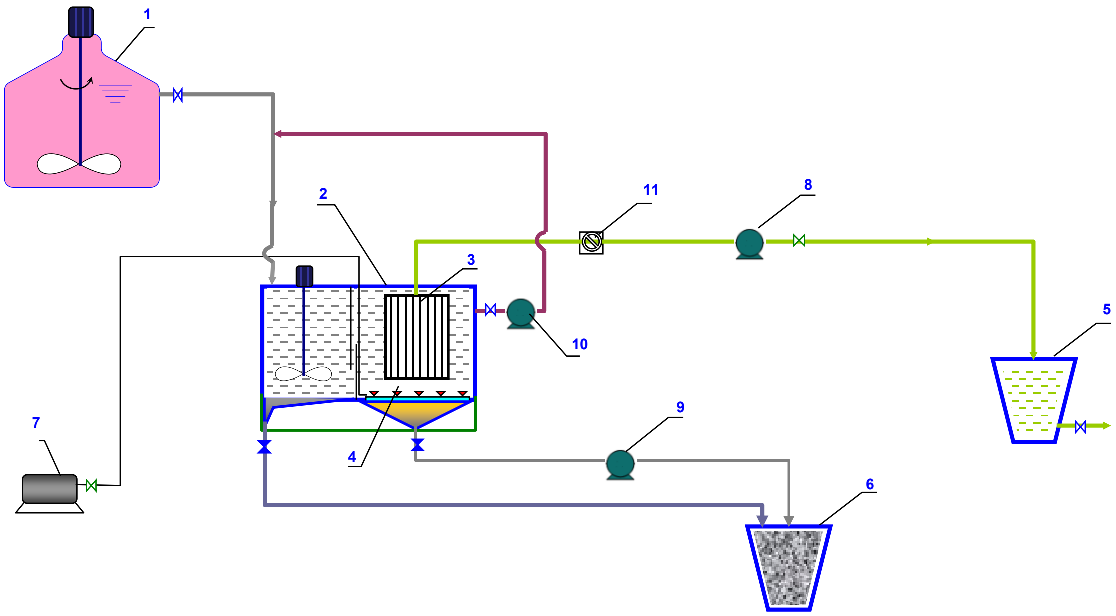

Figure 2. The schematic diagram of the A/O-MBR system: 1) Raw domestic wastewater tank; 2) Anoxic - oxic tank; 3) Mini-membrane module; 4) Fine air diffuser system; 5) Permeate tank; 6) Wasted sludge tank; 7) Air compressor; 8) Suction pump; 9) Sludge pump; 10) Mixed liquor recirculation pump

Table 3: Operation parameters

Period	Days	Influent flow rate Qin (L/h)	Return activated sludge flow rate Q_{RAS} (L/h)	HRT anoxic (hour)	HRT oxic (hour)	HRT total (hour)	Flux (m^3/m^2-day)	$COD_{inf.}$ (mg/L)	Loading rate V_{COD} ($kgCOD/m^3$-day)
1	1-30	10	1Qin	2h	2.5h	4.5h	0.24	200	1.07
2	31-60	5	1Qin	4h	5h	9h	0.12	180	0.48
3	61-120	5	2Qin	4h	5h	9h	0.12	192	0.52
4	121-150	8	3Qin	2.7h	3.1h	5.1h	0.19	220	0.94

3.2 Chemical analysis

The dissolved oxygen (DO), pH value, temperature of feed, permeate (effluent) and mixed liquor in the anoxic and aerobic tanks were measured daily by portable meters. The waters were also sampled 2 to 3 times per week and analyzed for chemical oxygen demand (COD), total nitrogen (T-N), ammonia nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), dissolved oxygen, temperature and pH. The concentrations of COD, T-N, NH_4-N, NO_3-N, mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) were analysed following Standard Method (APHA 2003) and HACH methods with the appropriate kits and a Spectrophotometer DR 2100 (HACH Company, USA).

4. Results and discussion

4.1 Profiles of operational parameters

During the first period of operation, the reactor was run at an influent flow rate of 10L/h and a corresponding flux of $0.24m^3/m^2$-day. The permeate filtration at this flux was maintained for 30 days. In the aerobic tank, the MLSS was not stable in the beginning as shown in **Figure 3-a**. The initial MLSS concentration in the aerobic tank was

2,000 mg/L. After 60 days, the MLSS concentration started to increase when the return sludge rate increased and got stable at the range of 3,000-4,000 mg/L until the end of period 3 (day 120th). The sludge concentration continued to increase steadily when increasing of feed flow rate and the sludge recirculation rate. During this period, the MLSS had reached as high of 5,600 mg/L. While MLSS concentration in the aerobic tank shows a relation with the change of HRT and sludge recirculation rate, the MLSS in anoxic tank remained stable over 150 days, ranging from 2,000-3,000 mg/L.

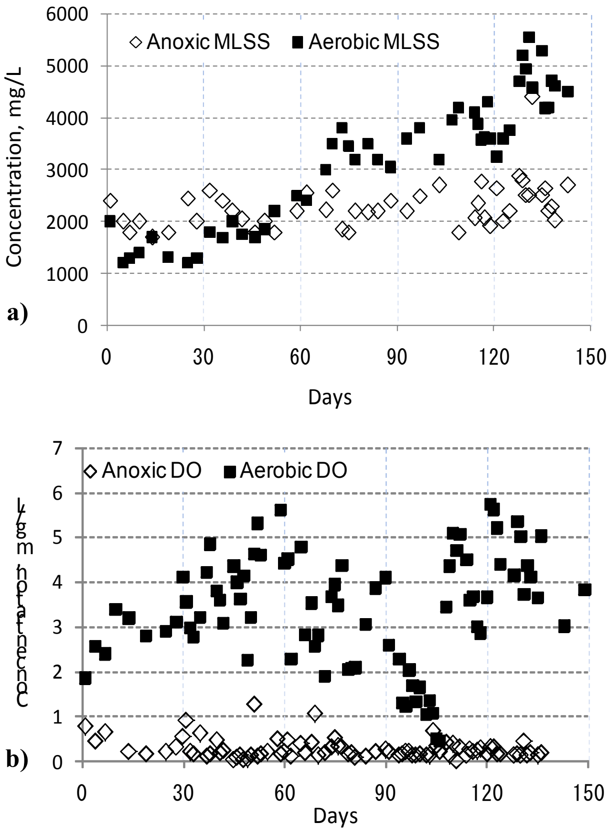

Figure 3. Concentration of a) MLSS and b) Dissolved oxygen in the bioreactor tank

During 150 days, a low MLSS concentration was generated at the aerobic tank when the reactor was operated at the different flow rates stated in **Table 3**. This lower concentration in the aerobic tank was desirable so as not to cause the failure of membrane filtration. It can also reduce energy requirements.

Dissolved oxygen concentrations in the aerobic and anoxic tanks are shown in **Figure 3-b**. Dissolved oxygen in the aeration tank on average ranged from 2.0 to above 5.0 mg/L. For a short period from day 95 to day 107, however, the dissolved oxygen in the aeration tank fell below 1.5 mg/L, probably because of the sharp increase of the ambient temperature (37-40^o), which may reduce the oxygen transfer rate and facilitate the biological processes. The lowest dissolved oxygen recorded was 0.46 mg/L. Dissolved oxygen levels in the anoxic tank were maintained below the 0.5 mg/L criteria for anoxic environment. Even when the return activated sludge recycle ratio was increased to 300 percent, the DO levels in the anoxic tank remained below 0.5 mg/L.

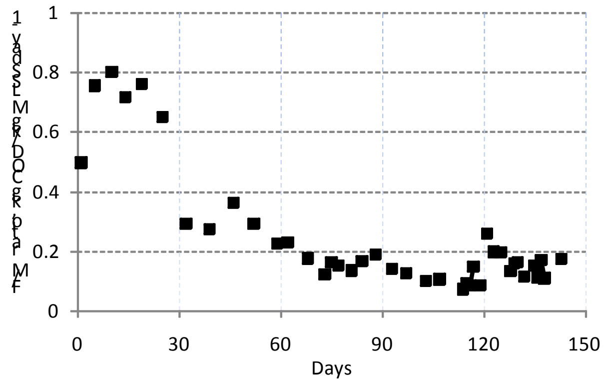

Figure 4. Profile of the food to microorganism (F/M) ratio during 150 days of operation

The profile of F/M ratio in the bioreactor is shown in **Figure 4**. After the first period (day 1-30), relatively low and stable F/M values were determined as a result of the low organics in the feed and the high concentration of sludge in the bioreactor. Low F/M, where substrate is limited compared to the population utilizing the substrate, can lead to conditions where low population growths are observed. During period 2 when the feed flow rate was 5L/h and the sludge circulation rate increased to 300%, the lowest F/M ratios were observed. The F/M ratios averaged about 0.1-0.15 kg COD/kg MLVSS-day, showing similar trend to that observed by Police et al. (2004) who determined an equilibrium F/M value of 0.15 kg COD/kg VSS-day in their study while Liu et al. (2005) obtained 0.1 kg COD/kg MLVSS-day.

4.2 Efficiency of the AO/MBR in removing wastewater pollutants

The concentration of COD, total nitrogen and ammonia nitrogen in the feed water and permeate are shown in **Figure 5**.

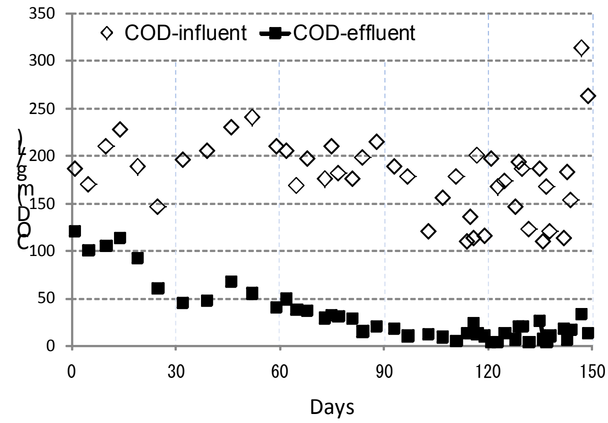

Figure 5. COD concentration in the feed and permeate over 150 days of operation

The COD concentration in the feed water varied from 110 to 240 mg/L. With this range of COD values, the feed water could be classified as low-strength wastewater. After the first period, COD in the permeate was below 50 mg/L which meets the standard for water discharge. The removal rate for COD was stable and high after day 80 with COD in permeate ranging from 4 to 20 mg/L. Thenafter, throughout the operation at different hydraulic retention times, the COD removal rates remained stable. During the period from day 95 to day 107 when the dissolved oxygen fell to below 1.5 mg/L in the aerobic tank, COD removal rates greater than 90 percent could still be achieved.

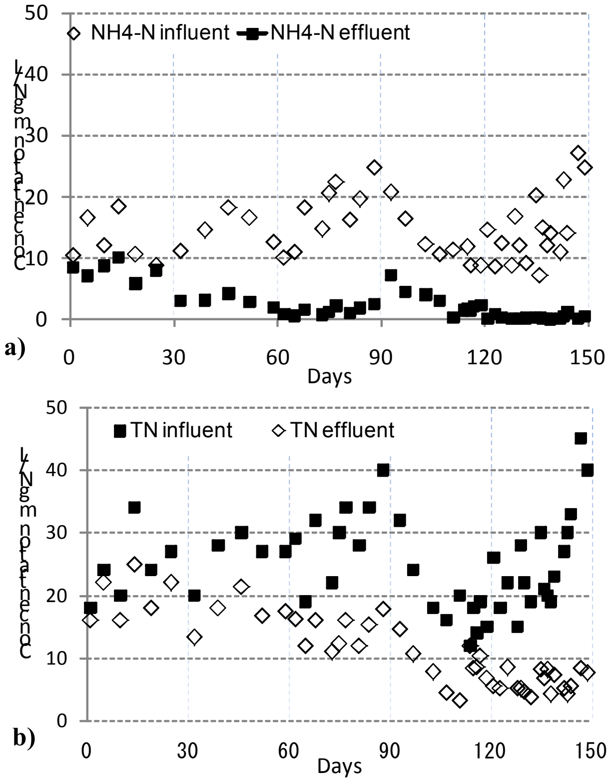

Figure 6. Concentration of a) Ammonia nitrogen and b) Total nitrogen in the feed and permeate

Total nitrogen in the feed ranged from 12.1 to 43.0 mg/L. To enhance the denitrification process for nitrogen removal, mixed liquor from the aerobic tank was returned continuously to the anoxic tank through the return activated sludge line at different recycle rates. For the first 30 days, the return activated sludge recycle ratio was set at 100% the influent flow rate. During this period, T-N in the permeate ranged from 16 to 28 mg/L, which is above the discharge limit. This start-up period could be considered an acclimatization stage for the microbial communities. Nitrifiers in particular are known to be slowly growing microorganisms and achieving stable nitrification/denitrification could take some time. The sludge recycle ratio was increased to 200% of the influent flow rate from day 60 to day 120 and to 300% from day 121 to day 150. The nitrogen removal rate was enhanced by increasing the return activated sludge ratio from the aerobic to the anoxic tank (**Figure 6-b**).

The concentration of ammonia nitrogen in the feed and permeate are shown in **Figure 6-a**. Ammonia nitrogen in the feed ranged from 7.4 to24.8 mg/L. This relatively high concentration of the effluent ammonia in the first period indicated that nitrification in the aerobic tank was not completed due to a short HRT in the aeration tank and week microbial activities for nitrification during start-up time. However, very good stable removal rate for ammonia (above 96%) could be achieved after day 30 and remain stable with higher rate associated with higher HRT and high recycle rate for the activated sludge.

The pH of feed, permeate and mixed liquor was from 6.89 to 7.73. Alkalinity of the feed water was above 230 mg $CaCO_3$/L and was above 80 mg/L in the effluent, indicating sufficient alkalinity for nitrification/denitrification processes in the bioreactor. During 150 days in operations, there was no backwashing or chemical cleaning needed except air scouring and pressure water cleaning. With a sludge retention time of about 60 days, the effluent water at the end of the investigation time still shows no sign of deterioration of effluent water quality.

In general, the results show a good removal rate for organic matter and nitrogen of the domestic wastewater by an A/O-MBR system. The organic removal rate was similar, but the removal of nitrogen was more stable and higher than then the existing A2O system in Kim Lien wastewater treatment plant. Further, during 5 months in operation, there is no need for external carbon sources and alkalinity adjustment for biological organic matter and nitrogen removal processes; as well as no PAC adding for enhancing of activated sludge settling.

5. Conclusions

A lab scale AO system with a hollow fiber membrane separation bioreactor was investigated for the treatment of low-strength domestic wastewater of Hanoi. Throughout the operation at different hydraulic retention times, the COD removal rate remained stable and high. Even when dissolved oxygen fell to below 1.0 mg/L in the aerobic tank, COD removal rates greater than 90 percent could still be achieved. The percent removal of total nitrogen increased with the increase of return activated sludge ratio to 200-300% of influent flow rate. Therefore, this system could be suitable to treat domestic wastewater in areas like Hanoi where the sewage is transported in combined system and where the sludge disposal is problematic due to the limited space available.

6. References

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