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Application of UMBR Coupled with MBR for Nitrogen Removal of Piggery Wastewater

Thanh Tuan Nguyen[1], Khoi Tran-Tien[1+], Dan Phuoc Nguyen, Hanh P.C. Nguyen, Kwon J.C.[2]

[1] Faculty of Environment, Hochiminh City University of Technology

[2] R&D Center, Ecodigm Co., Ltd., 306 DTV Post BI, Daejeon 305-501, Korea

Abstract. This study aimed to assess the use of UMBR coupled with MBR for piggery wastewater treatment in terms of COD and nitrogen removal. The feed wastewater, which was the effluent of biogas digester, contained 253 ± 49 mg/L as COD, 231 ± 18 mg/L as N-ammonia and 249 ±19 mg/L as TN, alkalinity of 1433 ±153 mg/L as CaCO3 and pH = 7.5 ± 0.3. Molasses and methanol were used as external carbon sources in this study. The same nitrogen removal efficiency of both molasses and methanol experiments obtained at COD loading of 0.53 kgCOD/m3.d, total nitrogen loading of 0.18 kgTN/m3.day where HRTs of UMBR and MBR were 21 h and 12 h, respectively. However, the COD and color removal of methanol experiment were better than those of molasses one. Runs at internal returns (from MBR to UMBR) of 200, 300 and 400% were carried out at COD loading of 0.59 kgCOD/m3.d, total nitrogen loading of 0.18 kgTN/m3.d with methanol as the carbon source. The result presented that the run at IR of 300% obtained the highest performance. Run at COD loading of 0.80 kgCOD/m3.d with total nitrogen loading of 0.16 kgTN/m3.d showed efficiency of COD, TKN, ammonia and color removal were 95%, 94%, 96%, and 80%, respectively. The effluent quality in terms of COD, TN, color and ammonia met the Vietnamese industrial effluent quality standards QCVN 40-2011/BTNMT (type B).

Keywords: UMBR, Piggery wastewater, Nitrogen removal

1. Introduction

Piggery farms annually emit a considerable amount of organic matter and high ammonia wastewater. Most farmers directly discharge wastewater to ambient environment, causing bad odour, poisoning the water and soil environment. According to a survey of Son (2011) for the small pig farms (size 100-400 pigs/batch) in Ho Chi Minh city, entire biogas-digester effluent did not meet the discharge standards (especially COD and nitrogen).

Piggery wastewater treatment by biological technologies bring high efficiency and low costs in investment and operating. The research in treatment of piggery wastewater by a bio-process – upflow sludge blanket filter (USBF) conducted by Canh (2010) showed COD, BOD_5, SS, nitrogen and phosphorus removal efficiency of 97%, 80%, 94% , 90% and 85%, respectively. The combination of three processes: anoxic, aerobic and bio-filtration brought about a great advantage in improving process efficiency, saving energy and materials of construction and operation.

The combination of biological processes in the same tank has been done by Kwon and colleagues (2003) in terms of research and application of Upflow Multilayer Biofilm Reactor (UMBR). UMBR is a hybrid system where anaerobic and anoxic process takes place in the same tank by suspended stratification in the tank. UMBR tank is described to have multiple functions such as a settling tank, an anaerobic tank, an anoxic tank and a sludge thickener. It requires less energy because the upflow direction of wastewater from the bottom layer of activated sludge in UMBR and increases the efficiency of treatment and sludge stabilization.

[+] Corresponding author. Tel.: + 84 977 068 984 ; fax: +84 8 38639682.
E-mail address: ttkhoi@yahoo.com.

2. Material and Method

2.1. Model Reactor and its Operation

The model reactors (shown in Fig. 1), an UMBR followed by a MBR tank, were fabricated by acrylic. The UMBR reactor was a cylinder with diameter of 90mm and height of 2000mm with the working volume of 12.7 litres. UMBR reactor was stirred by paddles (60x100 mm) arranged along a hollow shaft with rotation speed of 17 rpm. MBR reactor size was 150×100×600 mm, having a working volume of 7.5 litres. Microfiltration (MF) membrane was a submerged hollow-fiber type obtained from Motimo Membrane Technology (China). Suction hole diameter was 0.1 µm. Flux was 10-20 $l/m^2.h$, and the membrane area was 0.2 m^2.

The piggery wastewater was distributed from the bottom of UMBR reactor. The wastewater moved from the bottom up through multi-layer of sludge of anaerobic, anoxic and was collected by the weir and then flow by gravity into the MBR tank. The effluent was pumped out of the MBR tank at the rate of 0.75 l/h, giving a flux of 3.75 $l/m^2.h$. The mix liquor in the MBR tank was pumped back to UMBR reactor at the designed internal recirculation rates (100, 200, and 300 and 400%) for each study load in order to provide nitrate and nitrite (TNO_x) for denitrification in UMBR. The external carbon sources were supplied by adding methanol and molasses for comparative study.

MF membranes were periodically backwashed with 5% NaOCl solution when the trans-membrane pressure (TMP) increased to 25kPa or the flux decreased significantly so as to ensure the stability of the membrane and to limit the fouling when operating with high MLSS.

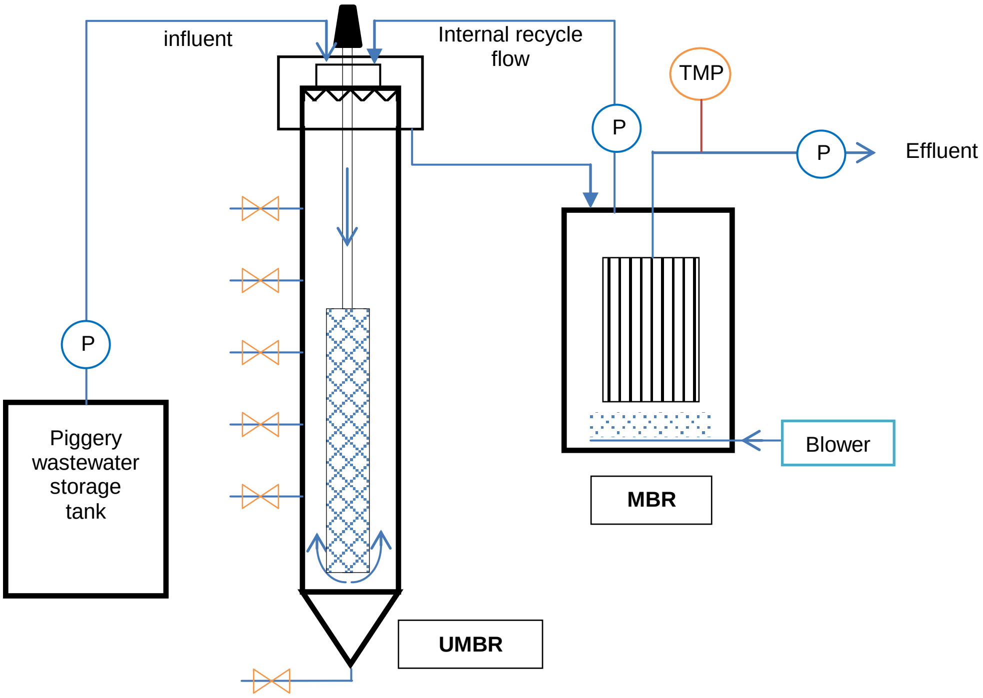

Fig. 1: The schematic diagram of the lab scale reactors

2.2. Feed Wastewater and Seed Sludge

Feed wastewater is piggery wastewater after a biogas digester with hydraulic retention time of about 20 days. Its COD, BOD5 and TN content were 253 ± 69, 131 ± 17 and 249 ± 19 mg/L respectively. The alkalinity was as high as 1433 + 153 mg/L.

Seed sludge used for experiments was collected from a clinical wastewater treatment pilot 10 m^3/d using UMBR technology. Anoxic sludge was taken from UMBR tank with initial sludge concentration was 7000 mg/L. Activated sludge was taken from the aerotank with initial sludge concentration was 3000 mg/L.

3. Result and Discussion

3.1. Comparison of the Carbon Sources for Denitrification Process

Fig. 2 presents the results of 3 experiments which were designed to compare the effect of different external carbon sources, where Exp1 was conducted without additional carbon, Exp2 with molasses as carbon source and Exp3 with methanol for nitrogen removal at IR = 200%.

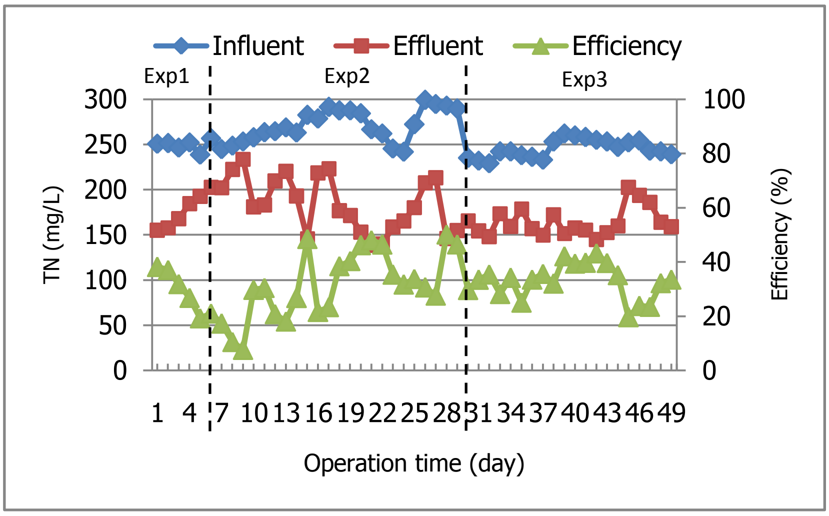

Fig. 2: Nitrogen removal by different sources of carbon

For Exp1, the output TN (178 ± 26 mg/L) was higher the discharge limit. The low efficiency on TN removal (28 ± 10%) was due to the high nitrate concentrations (NO_3-N = 128.8 ± 51.6 mg/L). The results were similar for both Exp2 and Exp3 whose nitrogen removal efficiencies were higher than that of Exp1 (1.3 times). The lowest nitrate removal efficiency was observed with Exp1 because the ratio COD: TN was 1. This ratio indicated that there was not enough carbon to meet the demand for denitrification process because it requires ratio bCOD:N = 3 (Jeanette and Carl, 2005). To increase the denitrification efficiency it needs external carbon source addition.

3.2. Comparison of the IRs for Denitrification Process

The study was carried out with IR = 200% (Exp3), IR = 300% (Exp4) and IR = 400% (Exp5). Methanol was added to influent that was mixed with the IR flow in order to create a substrate for the reduction TNOx.

According to Michael (2002), for complete denitrification of nitrate ions, 2.5 mg/L of methanol are required as the substrate per mg/L of nitrate ions, so the amount of methanol added to the experiment was 600 mg/L wastewater. The rate of COD was 65% methanol on total COD in Exp4.

It was obtained from the experiments that, with IR from 200% to 400%, the COD concentration after treatment (COD <150 mg/L) met discharge standards and IR 300% gave the highest COD removal efficiency (E = 94%). Nitrogen removal efficiency of the system increased with the IR change, efficiencies were 33 ± 13% (IR = 200%), 54 ± 11% (IR = 300%) and 57 ± 10% (IR = 400%). Denitrification efficiency increased by increasing IR because the amount of TNO_X flowing to UMBR tank increased. The ratio of reducing nitrate/COD consumption of IR at 200%, 300% and 400% were 0.06 ± 0.05, 0.30 ± 0.17 and 0.78 ± 0.48 (mgN/mgCOD), respectively. The TNO_X removal efficiency increased but nitrification effect decreased when IR increased from 300% to 400%. The increase in IR led to an increased capacity on the MBR tank, thus, hydraulic retention time decreased and nitrification occurred incompletely. During operation, the density of sludge in the MBR tanks reduced because larger circulation flow was pumped to the UMBR. Besides, the ratio F/M is low (F/M <0.1 kgCOD/kgMLSS.d), the rate of aerobic sludge produces slowly. Since nitrification occurs incompletely, both TNO_X produced in Exp5 and TNO_X in effluent were lower than that of Exp4. The results are illustrated in Fig. 3.

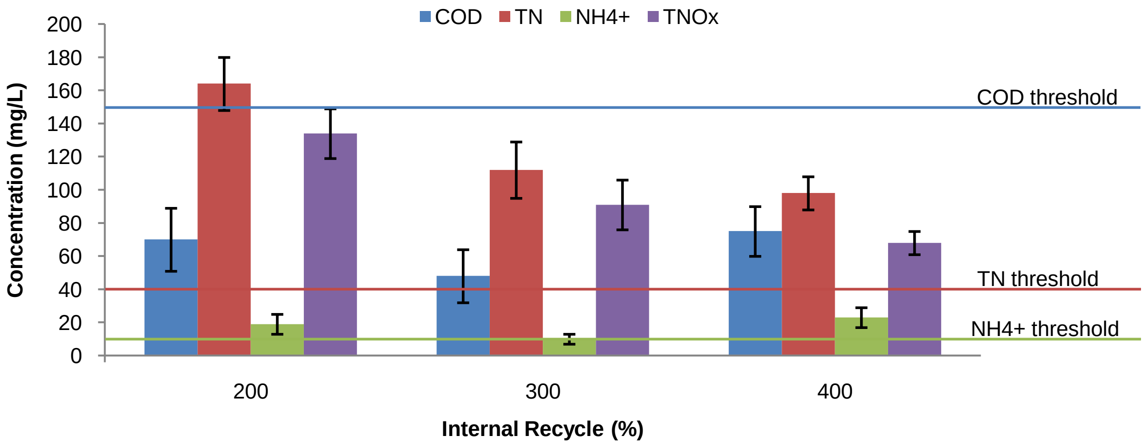

Fig. 3: Variation of effluent concentration with change of IR

Fig. 3 shows that the concentrations of COD and N-NH_4^+ in effluent of Exp4 were the lowest, while compared with IR = 400%, the nitrogen in effluent inconsiderably decreased (reduction is 14 mg/L). Therefore IR = 300% is the most effective treatment compared with the others.

3.3. Comparison of the COD Loading Compatible with Nitrogen Loading

Tests were carried out with two experiments Exp4 and Exp6. Results are shown in Fig. 4.

Fig. 4 shows that the effluent COD at L_{COD} = 0.8 kgCOD/m^3.d was 58 mg/L and met discharge standard (COD<150 mg/L), TN = 27 (<40 mg/L), NH_4^+ = 8 (<10 mg/L) and efficiency were 95%, 88% and 96%, respectively. At COD loading of 0.8 kgCOD/m^3.d, efficiency and effluent quality were higher than that at COD loading 0.59 kgCOD/m^3.d (in Exp4). COD and NH_4^+ removal efficiencies of the two loads were approximately similar (94% and 96%) but the nitrogen removal and denitrification efficiencies increased with increasing COD loading. Because UMBR had multilayer of sludge, the anaerobic process in the bottom of tank had treated a part of COD (equivalent to increasing load 0.20kgCOD/m^3.d). Thus the denitrification was incomplete because there was not sufficient carbon substrate at COD loading at 0.59 kgCOD/m^3.d. Effluent at COD loading of 0.8 kgCOD/m^3.d (corresponding to the nitrogen loading at 0.16 kgTN/m^3.d) met COD and nitrogen discharge standards QCVN 40:2011/BTNMT (type B).

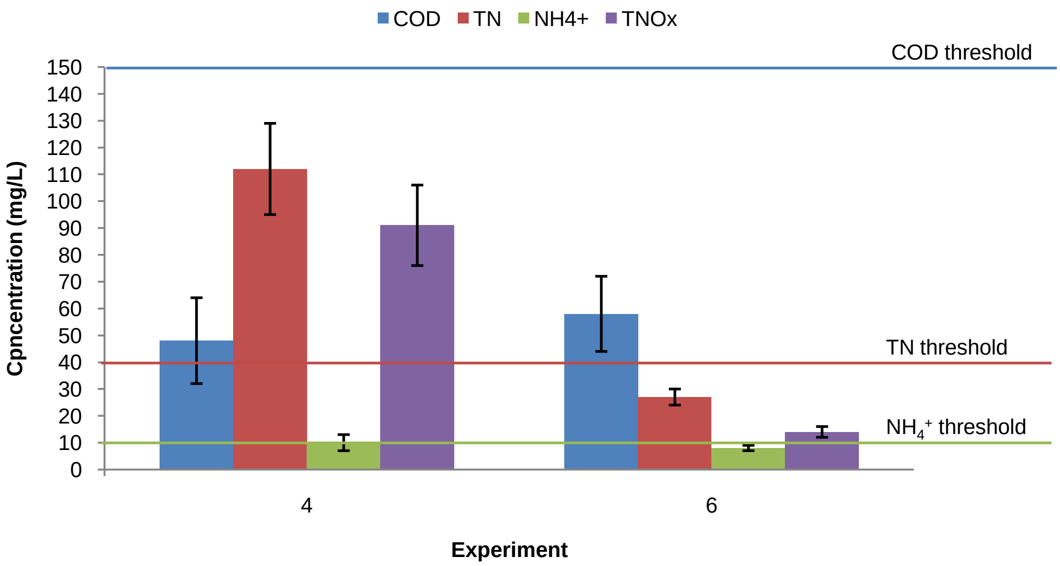

Fig. 4 Quality of effluent in Exp4 and Exp6

3.4. TMP Survey Value in the Study

Membrane resistance increased slowly and a stable value TMP = 14.4kPa were observed over 6 periods with an average MLSS in MBR tank of 5,500 mg/L. it was because the flux of the membrane operating at 3.75 $l/m^2.h$ lower than the manufacturer's design 10 $l/m^2.h$. In addition, high concentration of DO (4-5 mg/L) help membrane fouling decreased significantly. In Exp1 to Exp5 membrane backwash process was done in the end each experiments. Exp6 necessary to wash the membrane after 14 days of operation due to high density sludge and the membrane passed 5 months of continuous use.

4. Conclusion

Piggery wastewater after biogas tank contained nitrogen concentration of 5 times higher than discharge standard. External carbon substrate (methanol) must be used to perform nitrogen removal by nitrification and denitrification method because of COD concentration was not sufficient to denitrification.

The highest treatment efficiency was observed at IR of 300%. IR of 200% did not provide enough nitrate to complete removal in UMBR whereas IR of 400% reduced the oxidation of ammonia to nitrate.

The effluent at L_{COD} = 0.8 $kgCOD/m^3.d$ (corresponding L_{TN} = 0.16 $kgCOD/m^3.d$) and IR = 300% met discharge standards QCVN 40-2011/BTNMT (type B) of COD and nitrogen.

UMBR coupled with MBR are suitable for piggery wastewater treatment. The effluent complied with discharge standard and this process can be applied widely to small and medium scale industries.

5. Acknowledgement

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