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Application of upflow multi-layer bioreactor (UMBR) for domestic wastewater treatment in HCMC

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Abstract. Up-flow multi-layer bioreactor (UMBR) is a hybrid system using dual sludge that consists of an up-flow multi-layer bioreactor as anaerobic/anoxic suspended growth microorganisms followed by an aeration tank. The UMBR acts as a primary settling tank, anaerobic/anoxic reactor, thickener which requires low energy due to mixing by up-flow stream. This study focused on using a pilot UMBR plant with capacity of 20-30 m^3/day for domestic wastewater in HCMC. HRTs of UMBR and aeration tank were 4.8 h and 7.2 h, respectively. The average MLSS of UMBR ranged from 10,000-13,600 mg/l SS. Internal recycle rate and sludge return were 200-300% and 150-200%, respectively. The results obtained from this study at flow rate of 20 m^3/day showed that removal of COD, SS, TKN, N-NH_4, T-N, and color were 91%, 87%, 86%, 80%, 91% and 91%, respectively.

Keywords: UMBR; up-flow multi-layer bioreactor; nutrient removal; domestic wastewater

1. Introduction

UMBR is a hybrid system using dual sludge that consists of an up-flow multi-layer bioreactor (UMBR) as anaerobic/anoxic reactor with suspended growth microorganisms. The UMBR acts as a primary settling tank, anaerobic/anoxic reactor, thickener, and requires low energy by mixing using the up-flow stream. Plug flow reaction by the up-flow mode can be allowed to maintain high biomass. In order to overcome defects of a fixed influent distributor in UASB (up-flow anaerobic sludge blanket), distributors at the bottom of the UMBR are attached to rotating shaft at a low revolution rate to uniformly feed influent and to prevent channeling effects (Kwon *et al*. 2005).

Recently, UMBR process was studied and applied effectively to the different wastewaters such as swine wastewater, sewage wastewater especially in South Korea (An *et al*. 2007, Kwon *et al*. 2003). Kwon *et al*. (2005) studied a pilot UMBR for sewage treatment at HRT of 5.8 h and 6.4 h for UMBR and aerobic reactor, respectively. The removal of COD and TN were 93%, 75%, respectively (An *et al*. 2007). It was also reported that by using UMBR for strong nitrogenous swine wastewater, high COD removal of 94% and nitrification higher than 98%)were obtained (Kwon *et al*. 2003). However, the researches on UMBR process in other places outside South Korea are still very limited due to its recent invention.

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Until 2010, there was one domestic central wastewater treatment plant (DWWTP) with capacity of 141,000 m^3/day and two decentralized DWWTPs with capacity higher than 10,000 m^3/d in Ho Chi Minh City. All of them met the Vietnamese effluent quality standard (QCVN 14: BTNMT/ 2008, class A), except ammonia concentration. The effluent ammonia of Binh Hung Hoa DWWTP ranged from 3.1 to 19 mg/L as N (Institute for Environment and Natural Resource 2005).

To improve effluent quality, application of UMBR process was an option for nitrogen removal of domestic wastewater in HCMC. An UMBR pilot scale experiment with capacity of 30 m^3/day was run at Binh Hung Hoa DWWTP during December 2009 to August 2010.

2. Materials and methods

2.1 The UMBR pilot plant

The UMBR pilot plant includes UMBR followed by completed mixing activated sludge reactor (AS) and secondary clarifier (Fig. 1). The square UMBR has a total volume of 4.95 m^3, an internal dimension of 1.5 m × 1.5 m and a height of 2.2 m, corresponding to working volume of 4.0 m^3. The aeration tank has a capacity of 6.6 m^3, a width of 2 m, a length of 1.5 m, and a height of 2.2 m, a working volume of 6.0 m^3. The clarifier has a working volume of 4.0 m^3, an internal diameter of 1.5 m. The influent wastewater, internal recycle from the aeration tank and sludge return from the circular clarifier were fed uniformly into the bottom of the UMBR by the rotating distributor via the feed-well situated at the top of the UMBR. The distributor and vertical/horizontal baffles are attached to the shaft of the cycle-reducer, to prevent short- circuits of the influent and the channeling effect between the solids and water. The UMBR is divided into two layers on the basis of the up-flowing position; first, the dense sludge layer with a depth less than 1.0 m, below the distributor acts as a thickener, in which excess sludge can be concentrated from 20,000 up to 40,000 mg/L. Secondly, the reaction layer above the distributor acted as an anaerobic or anoxic reactor, which could be controlled by adjusting the recycle rate depending on internal recycle and return activated sludge (RAS).

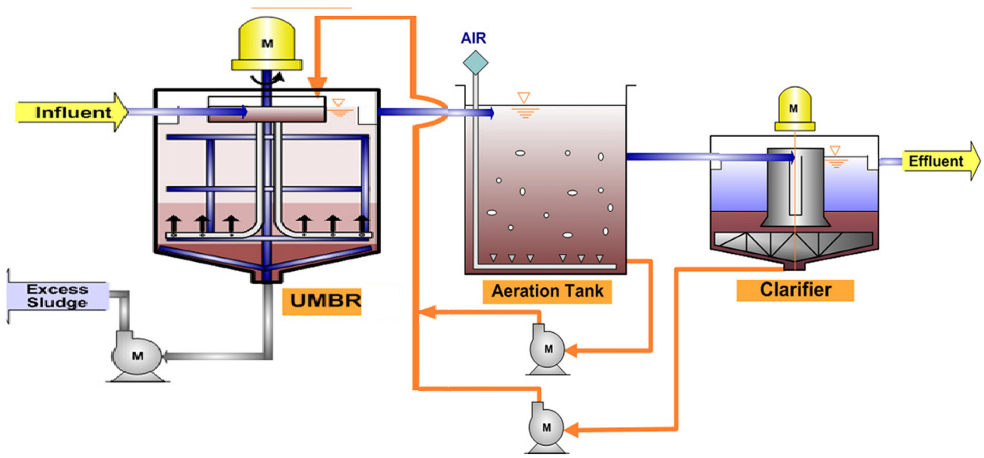

Fig. 1 The schematic diagramof the pilot scale plant

2.2 Feed wastewater and seed sludge

Feed wastewater was the effluent from the grit chamber of Binh Hung Hoa DWWTP. Characteristics of feed wastewater were COD 178±36 mg/L, TKN 31±7 mg/L, TP 10±5 mg/L, color 311±159 Pt-Co, turbidity 165±52 FAU, SS 97±52 mg/L and alkalinity 190±29 mg$CaCO_3$/L.

The seed sludge was the dewatered activated sludge taken from central wastewater treatment plant of Tan Tao industrial park. The initial MLSS in UMBR as well as aeration tank was 1,500 mg/l.

2.3 Operational condition

Operation conditions for the pilot scale plant during this study are described in Table 1. The average influent flow rate was 20-28 m^3/d and total hydraulic retention time (HRT) of the pilot plant was 8.3-12 h, in which the average HRT of UMBR and AS was about 3.3-4.8 h and 5.0-7.2 h, respectively. The average MLSS of the sludge blanket in the UMBR varied from 5,184±2,685 mg/l. The high removal rate of nitrate and organic matter were only obtained because high MLSS concentration of more than 10,000 mg/L (Kwon *et al*. 2003). The internal recycle rate from the AS reactor was 200% of influent flow rate.

2.4 Analytical methods

COD, SS, TN, TKN, NH4+-N, NO_2-N, NO_3-N, TP, alkalinity, color, turbidity, mixed liquor suspended solids (MLSS), and mixed liquor volatile suspended solids (MLVSS) were analyzed according to Standard Methods (APHA-AWWA-WEF 1998). pH and DO were measured by using pH meter (HI 8314, Hanna) and DO meter (HI 9146, Hanna), respectively.

Table 1 Operation conditions of the UMBR pilot plant

Items		Run 1	Run 2
Influent flow rateQ_{inf}, m^3/d		20-22	30
Internal recycle, % Q_{inf}		300	180-200
Sludge return, % Q_{inf}		200	150
Average COD loading rate, kg COD/m^3/day		0.35	0.50
HRT, h: ($V_{reactor}/Q_{inf}$)			
-	UMBR	4.8	3.4
-	AS	7.2	5.1
MLSS of top layer in UMBR, mg/L		2200-7600	4000-8700
Average MLSS of bottom layer in UMBR		8600-11000	11000-14500
MLSS of AS reactor, mg/L		6200 ± 2700	4400 ± 1120
F/M ratio: kg COD/kgMLSS/day		0.075	0.085
kg BOD_5/kgMLSS/day		0.047	0.05
Surface loading rate of clarifier: m^3/m^2/day		34	4
kg SS/m^2/day		210	190
SRT, days		26	20

3. Results and disscussion

3.1 COD, SS, and color removal

Removal performances of COD, SS and color by the pilot plant are shown in Figs. 2, 4 and 5. Results obtained by the pilot plant are summarized in Table 1. The average effluent concentration of COD, SS, and color were 40 ± 29 (SD) mg/L, 41 ± 48 mg/L, and 60 ± 24 Pt-Co, corresponding to a removal efficiency of 78 ± 14%, 60 ± 32%, and 796%, respectively. The effluent COD, SS and color were met the allowed values of the industrial wastewater quality standards (QCVN 24:2009/BTNMT, type B). Fig. 1 shows that influent COD was removed mostly by UMBR. The UMBR performance was about 91% of total COD removal of the whole pilot plant. The aeration tankreactor was run at very low F/M (0.03 kgCOD/kgMLSS/day), similar to an extended AS process, in which nitrification and stabilization of sludge mainly tookplace.

Fig. 3 shows that the average effluent COD concentration at loading rates of 0.34 and 0.5 kg COD/m^3/d were less than 50 mg/L. There was not significant difference between two runs in term of COD removal. This was explained that F/M ratios of both COD loading rate were not different

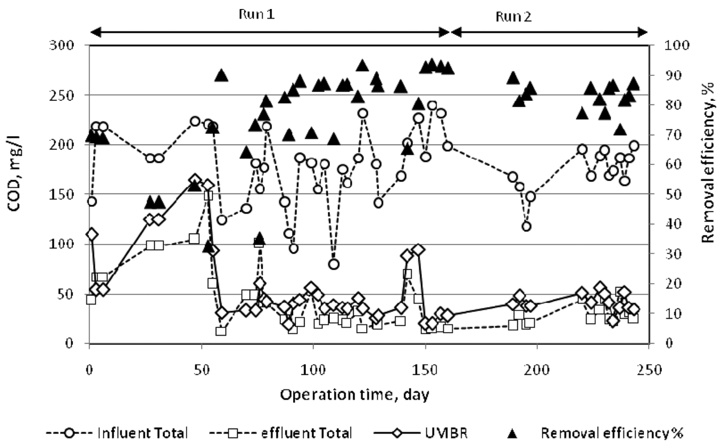

Fig. 2 Change in COD concentration and removal during the UMBR experiment

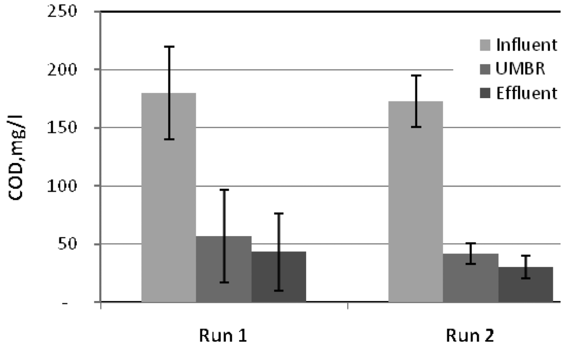

Fig. 3 The average effluent COD concentrations at different runs

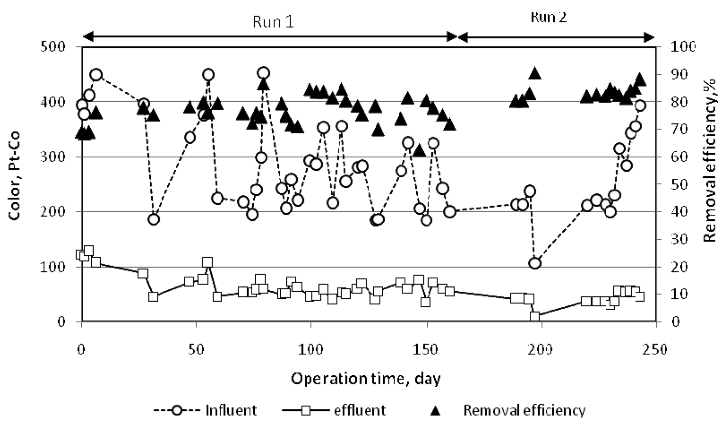

Fig. 4 Change in color value and color removal during the UMBR experiment

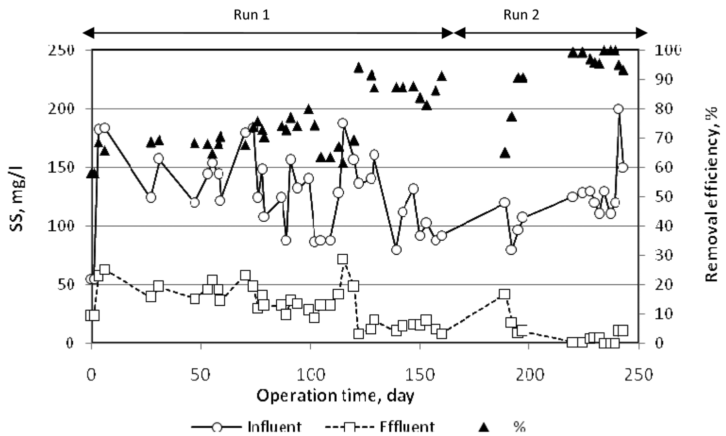

Fig. 5 Change in SS during UMBR experiment

(Table 1). In general, previous research has proved that extended AS can run at F/M ratio of 0.1-0.3 kg COD/kgMLSS/day (Eckenfelder Jr. 2000). This results demonstrated that the pilot plant might able to runat COD loading rate higher than 0.5 kg COD/m^3/day to examine the COD removal efficiency of UMBR process with high organic loading rate in future work.

Beside organic removal, the UMBR also obtained high color removal (Fig. 4). The raw wastewater contained high color that was originated from many small-scale textile and dyeing industries located in the residential areas surrounding Binh Hung Hoa WWTP. High color removal may due to absorption of dyes into bioflocs of the UMBR.

Fig. 5 shown that SS removal in run II was higher than that of run I, even though hydraulic load of run I (20 m^3/day) was lower in run II (28 m^3/day). It was easily observed that much fine biofocs appeared in the run I. The reason could be (i) longer SRT (26 days) maintained in run I and (ii) high solid loading rate of clarifier in run I. In order to enhance effluent SS, decrease of solid loading rate to less than 100 kgSS/m^2/day was necessary.

Similarly, higher color removal in run II was observed. It may explain that shorter SRT can increase high color removal.

3.2 Nitrogen removal

Figs. 6, 8, and Table 2 shows that average effluent TN, ammonia and nitrate concentration in both Runs met the Vietnamese standards. The nitrification efficiency of AS reactor was 80%± 18 while the effluent NH_4-N was 1.0-4.7 mgN/L during the whole experiment. Table 2 shows that higher nitrification performance in run I (76%) was higher than that in Run II (56%). Whereas,the influent nitrate concentration from the recycled flowin both Runs were removed completely by the UMBR. Thus, in order to enhancehigh effluent quality in terms of low NO_3^-, and TN in run II, the internal recycle flow should be increased.

The MLSS in the AS tank was maintained in therange of 3,300-8,900 mg/L, which the average solid loading rate of clarifier was in range of 190-210 kg SS/m^2/day. High solid loading rates resulted in high suspended solids (Fig. 5).

As shown in Fig. 9, the average bottom sludge concentration in UMBR was 8,500 mg/L and 13,500 mg/L SS in run I and Run II, respectively. The average upflow velocity was range 2.3-2.5 m/h, corresponding to average actual HRT of UMBR of 0.9 h. Thickened layer in the UMBR with

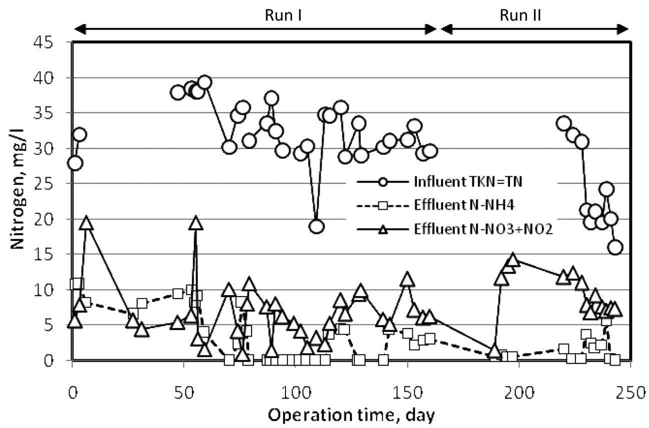

Fig. 6 Change in nitrogenous compounds during the UMBR experiment

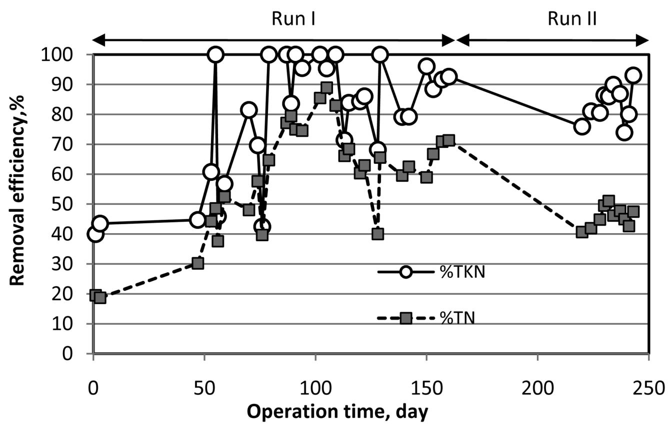

Fig. 7 Removal performances of TN and TKN

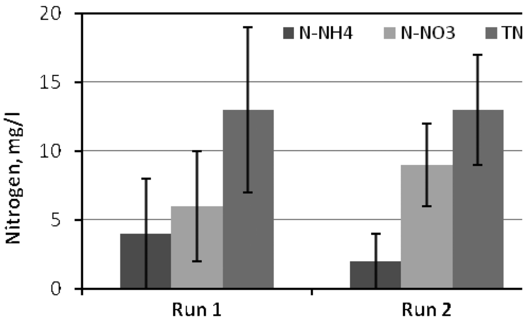

Fig. 8 Average effluent N-NH_4, N-NO_3, N-NO_2 concentraions at different runs

Table 2 Removal performance of the UMBR pilot plant

	Influent	UMBR	Effluent	E(%)	Vietnamese standards
SS (mg/l)	97±50		**41.0±48.0**	60.0±32.0	**50⁽¹⁾**
- Run 1	95.6±49.9	-	53.5±50.5		
- Run 2	134.3±35.02	-	5.7±5.3		
BOD_5 (mg/l)	111±29	Na	**20.0±13.0**	81.0±6.0	**30⁽¹⁾**
- Run 1	111±29	Na	20.0±13.0		
- Run 2	na	Na	na		
COD (mg/l)	178±36	52±34	**40.0±29.0**	78.0±14.0	**100⁽²⁾**
- Run 1	180.0±40.0	56.6±39.9	43.0±33.0		
- Run 2	173.0±22.0	41.8±9.0	30.0±10.0		
TKN (mg N/L)	30±6	15±7	6±6	81.0±17.0	-
- Run 1	33.3±6.2	18.3±14.6	6.2±6.2		
- Run 2	23.9±6.1	13.1±2.2	4.2±2.1		
TN (mg N/L)	30±6	18.1±12.6	**13.0±6.0**	57.0±16.0	**30⁽²⁾**
- Run 1	33.3±6.5	19.5±14.0	14.5±7.2		
- Run 2	23.9±6.0	13.5±2.1	14.8±3.3		
NH_4-N (mg N/l)			**3.0±3.0**	80.4±17.8	**5⁽¹⁾**
- Run 1	22.1±5.7	10.1±9.5	4.7±4.5		
- Run 2	17.1±3.7	7.2±3.4	1.0±0.7		
NO_3-N (mg N/l)		1.2±1.2	**7.2±4.1**		**30⁽¹⁾**
- Run 1	-	1.2±1.2	8.0±5.3	76%	
- Run 2	-	0.4±0.1	10.6±3.0	56%	
NO_2-N (mg N/l)		0.12±0.11	0.23±0.2		
- Run 1	-	0.1±0.1	0.2±0.2		
- Run 2	-	0.02±0.01	0.03±0.02		
Color (mg Pt-Co/l)	279±83	105±68	**60.0±24.0**	79.0±6.0	**70⁽²⁾**
- Run 1	289.1±83.9	114.3±75.5	66.8±23.7		
- Run 2	277.5±70.8	86.1±42.3	44.5±8.9		
Turbidity (FAU)	196.0±48.0	45±30	9.0±9.0	94.0±5.0	
- Run 1	166.0±48.5	47.2±30.8	10.7±10.1		
- Run 2	181.8±46.8	23.7±13.5	4.1±3.9		

Note: (1) - Domestic effluent quality standards
(2) - Industrial effluent quality standards
Sample number n =36 (run 1)
Sample number n =10 (run 2)

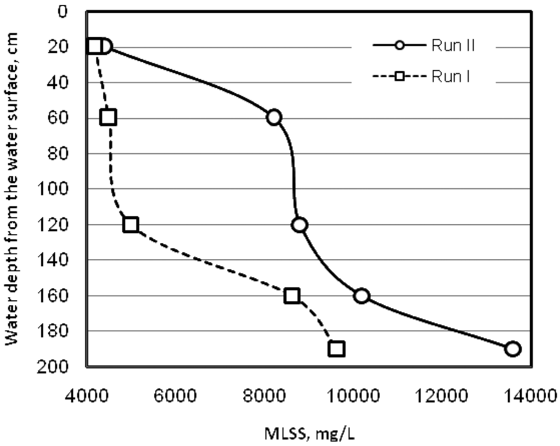

Fig. 9 Sludge profile of UMBR

suspended solids of more than 8,000 mg/L was at the depth of 150 cm from the water surface towards the bottom. The sludge layer in UMBR played significant role of influent SS and color removal as catchment or absorption of colloidal solids or dye compounds. The sludge layer in UMBR obtained average true color removal of 61 and 70% at run I and Run II, respectively (Table 2).

4. Conclusions

The following conclusions were drawn from this study:

- The UMBR pilot plant obtained high COD, nitrogen and color removal. The effluent quality met the Vietnamese effluent quality standards.
- The sludge layer in UMBR played the important role of color removal, BOD and denitrification.
- High performance of nitrification was obtained by the aeration tank reactor operated at low F/M ratio less than 0.1 kg COD/kg MLSS/day
- Removal of total nitrogen could be improvedas internal cycle rateincreased.

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