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Simultaneous Organics and Nutrients Removal from Domestic Wastewater in a Combined Cylindrical Anoxic/Aerobic Moving Bed Biofilm Reactor

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Abstract: The aim of present study was to design and construct an continuous up-flow pilot scale Moving Bed Biofilm Reactor (MBBR) which is consists of combined cylindrical Anoxic/Aerobic MBBR in nested form with anoxic/aerobic volume ratio equal to 0.16 to treated 4 m^3/days of domestic wastewater in Chongqing city at Southwest China. The treatment must be satisfactory to meet with grade B of discharge standard of pollutants for municipal wastewater treatment plant in China (GB/T18918-2002). Kaldnes (K1) media was used as a carrier in both reactors at a media fill ratio equal to 50%. The reactors was operated under the Anoxic/Oxic (An/O) process which must meet stringent TN limits without sludge returning into the system and only an internal recycling was performed from aerobic to anoxic reactor. After developing the biofilm on the media, reactor was operated at 3 different Hydraulic Residence Time (HRT) ranging from 4.95 to 8.25 h. During operation the internal recycle ratio to eliminate nitrogen compounds were 100% of inflow rate and the average Dissolved Oxygen concentration (DO) in aerobic and anoxic MBBRs were 4.49 and 0.16 mg/L, respectively. The obtained results showed that the HRT of 6.2 h was suitable for simultaneous removal of COD, NH_4^+-N, TN and TP. In this HRT the average removal efficiencies were 93.15, 98.06, 71.67 and 90.88% for COD, NH_4^+-N, TN and TP, respectively.

Keywords: Ammonium nitrogen, anoxic, assimilation, attached biomass, autotrophic microorganisms, biofilm, biological treatment, carrier, conventional activated sludge process, denitrification, gas/water ratio, heterotrophic, integrated fixed-film activated sludge, nitrate, nitrification, nitrite, nitrobactor, nitrogen, nitrosomanas, oxic, phosphorus, sequencing batch moving bed biofilm reactor, suspended biomass

INTRODUCTION

Today the need for clean water is rapidly increasing as the world's population grows by each year. The new awareness about the decreased rainfall that is expected in large parts of the world due to climate change and urbanization, which accumulate large amounts of people in cities, calls for efficient wastewater treatment facilities while reducing the available land area to build new wastewater treatment plants. In order to face this challenge there is necessity of finding new treatment method which can produce higher quality effluent while having minimum foot print.

Biological treatment of domestic wastewater by Conventional Activated Sludge process (CAS) has been practicing for more than 100 years. Due to the stringent rules and regulations in disposal of treated effluent to environment now a days there is a bloom in finding new treatment methods and process modifications to existing processes. Since then activated sludge process modified numerous times in order to produce higher quality effluent. Even at present conventional activated sludge process considered as one of the most widely used and most economical ways of treating wastewater containing organic pollutants. Operational problems drastically reduced the efficiency of conventional activated sludge process. Most common operational problems in CAS are sludge bulking, sludge rising and Nocardia foam. Therefore generally CAS needs more attention by conducting frequent analytical tests and having an experienced crew to look after the system. Higher hydraulic retention time requirement is another drawback of CAS and this leads to higher tank volumes, finally end up in large foot print. Situation becomes worse when treating wastewater for nutrients in wastewater such as nitrogen and phosphorus, because the removal takes more time compared to other organic matter. In the last years, the idea to combine the two different processes (attached and suspended biomass) to increase the performances of an existing CAS system by increase the amount of biomass inside the reactor.

Moving Bed Biofilm Reactor (MBBR) was introduced in order to overcome some of the draw backs identified in the Conventional Activated Sludge (CAS) process. The moving bed biofilm process

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differs from the activated sludge process in that the latter is operated with the activated biomass suspended in the system, while the former is operated with biomass both the attached biomass in the biofilms which grow and adhere to the surface of the carriers and the suspended biomass in the system (Park *et al*., 1995, 1996 a, b). The first Moving Bed Biofilm Reactor (MBBR) facility became operational in early 1990 in Norway and then was developed in Europe and United State of America. In 2000, there have been more than 400 large-scale wastewater treatment plants based on this process in operation in 22 different countries all over the word (Maurer *et al*., 2000).

The MBBR process is based on the biofilm principle that take advantage of both activated sludge process and conventional fixed film systems without theirs disadvantages. The idea of the MBBR process is a continuous flow process which combine the two different processes (attached and suspended biomass) by adding biofilm small High Density Polyethylene (HDPE) carrier elements with a large surface area and a density slightly less or heavier than 1.0×10^3 kg/m^3 into the tank for biofilm attachment and growth has been proposed. This kind of system is usually referred as IFAS (Integrated Fixed-film Activated Sludge) process (Sriwiriyarat and Randall, 2005). The carrier elements can be installed in either anaerobic, anoxic reactor or aeration basin, the carrier media that is added for the growth of the attached biomass it can be fixed or freely moving inside the reactor. In this latter case, when the media is used on its own, the process is usually called Moving Bed Biofilm Reactor (MBBR) (Germain *et al*., 2007). The agitation pattern in the reactor is designed to provide an upward movement of the carriers across the surface of the retention screen which creates a scrubbing effect to prevent clogging, so that the whole reactor volume is biologically active resulting in higher biomass activity. Therefore the reactor can be operated at very high load and the process is insensitive to load variations and other distributances (Odegaard *et al*., 1994; Delenfort and Thulin, 1997). Unlike most biofilm reactors, the reactor volume in the MBBR is totally mixed and consequently there is no dead or unused space in the reactor. In addition, this system has a small head loss and no need for recycling of biomass or sludge (Xiao *et al*., 2007).

Wastewater containing high levels of phosphorus and nitrogen cause several problems, such as eutrophication, oxygen consumption and toxicity, when discharged into the environment. It is, therefore, necessary to remove such substances from wastewaters in order to reduce their harm to the environment. Therefore the regulations on the Nitrogen (N) and Phosphorus (P) contents in wastewater discharge are increasingly more stringent, for controlling the rate of eutrophication in the aquatic environment.

Total nitrogen in domestic wastewater consists of about 60% of ammonium nitrogen and 40% organic nitrogen. By using conventional primary and secondary treatment processes some part of the organic nitrogen which is associated with settle able solids can be removed. Most of the dissolved and colloidal organic and dissolved inorganic forms of nitrogen will be in the

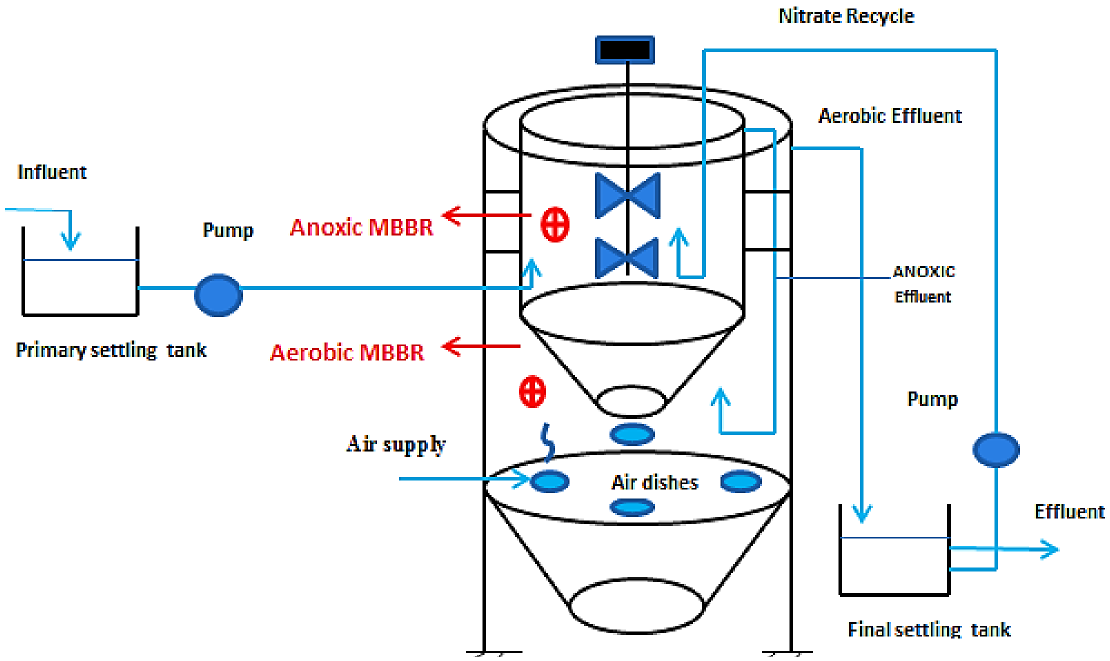

Fig. 1: Schematic diagram of pilot-scale MBBR system

wastewater without affected. Nitrogen can be removed from the wastewater by advance biological processes, but addition of the tertiary treatment unit will increase the overall treatment cost as well as the land requirement. The removal of nitrogen can be achieved by two main processes; namely assimilation and nitrification-denitrification (Grady *et al*., 1999; Schmidt *et al*., 2003; Gee and Kim, 2004). In assimilation part of the total nitrogen is converted in to cell biomass by microorganisms. In nitrification-denitrification nitrogen removal takes place by two steps. In the first step ammonium nitrogen converts into nitrite by autotrophic microorganisms called Nitrosomanas and further oxidized into nitrate by Nitrobactor. The second step is the conversion of nitrate in to nitrogen gas which is known as denitrification. Generally, the two treatment activities are carried out in physically separated oxic and anoxic treatment zones (Ju *et al*., 1995).

MATERIALS AND METHODS

Experimental set-up: The reactors was built in the DADUKOU wastewater treatment plant which is located in DADUKOU district in Chongqing city at Southwest China. The experiments were conducted using two steel pilot scale MBBRs with anoxic/aerobic volume ratio equal to 0.16. Reactors were constructed in the form of overlapping cylinders by puts the anoxic reactor inside the aerobic reactor to reduce the required land area. Sludge recycling was not implemented in this process. The anoxic reactor (R_1) was designed to achieve the denitrification processes by provide the major portion of nitrate removal. The aerobic reactor (R_2) was designed to achieve the nitrification processes. The phosphorus will be removed according to both anoxic and aerobic processes. A sketch of the lab-scale moving bed biofilm reactors is shown in (Fig. 1) and some key parameters are listed in Table 1. Anoxic cylindrical MBBR with diameter (D = 0.6 m) and total depth (H = 0.9 m) was made of steel plate (5 mm thick) and located inside the aerobic cylindrical MBBR (D = 1.2 m and H = 2 m) which also was made of steel plate (5 mm thick). The effective depth of the anoxic and aerobic reactors equal to 0.5 and 0.95 m, respectively. Both anoxic and aerobic MBBRs were operated in an up-flow mode, Kaldnes (K_1) media was used as a carrier in both reactors at a media fill ratio equal to 50%. The Kaldnes (K_1) carrier elements are made of polyethylene (density 0.93 g/cm^3) and shaped like small cylinders (about 25 mm in diameter and 10 mm long) with a cross inside as shown in (Fig. 2) to provide sites for active bacteria attachment in a suspended growth medium. The effective specific growth area is 500 m^2/m^3 at 100% filling grade, Table 2 show the characteristics of the Kaldnes (k_1) media which used in this study The biofilm carrier elements are kept suspended in the water by air from the diffusors in aerobic reactor and by means of propeller mixer in anoxic reactor. The propeller mixer consist of central, 2-blade double stirrer of 25 cm diameter and with blades placed at 20 and 40 cm below top-water level, the stirrer speed was 100 rpm. The carrier elements are retained by means of small sized sieve (about 2 mm opening). Sampling ports were provided in each reactor by using DN10 UPVC pipes for sample collection in the top, middle and bottom.

Table 1: Technical data and key parameters for the anoxic-aerobic MBBRs

Parameter	Anoxic MBBR (R_1)	Aerobic MBBR (R_2)
Effective volume (m^3)	0.141	0.89
Filling ratio with bio-carriers (%)	50	50
Specific biofilm surface area (m^2/m^3)	250	250
Total biofilm surface area (m^2)	35.250	222.50
Flow rate (m^3/day)	4	4
Flow direction	Up-flow	Up-flow

Table 2: The characteristics of the Kaldnes (k_1) media

Parameter	Value
Dimension (mm)	25×10
Surface area (m^2/m^3)	500
Filling ratio (%)	15-65
Density (g/cm^3)	0.93
Number/m^3	150,000
Voidage (%)	95
Oxidation efficiency of BOD_5 (g BOD_5/m^3.d)	6000
Hanging coefficient (g/carrier)	1.30

Fig. 2: Kaldnes (K_1) carriers

The domestic wastewater reached to the square primary settling tank (made of PVC 1×1×1 m) from the preliminary treatment part in Dadukou wastewater treatment plant which is responsible for removal of wastewater constituents such as rags, sticks, floatable, grit and grease that may cause operational problems with the treatment operations. The main purpose of the establishment of the primary settling tank is to remove part of suspended matter and organic material by settling, this method protect the pumps and pipes from clogging also improve subsequent biological treatment and keep stable water quality. The anoxic MBBR was continuously received the domestic wastewater from the square primary settling tank in the start-up mode and from both the square primary settling tank and the square final clarifier (made of PVC 1×1×1 m) in steady state mode by using magnetic circulation pumps model MP-30RZM with maximum capacity and maximum head equal to 15-17 (L/min) and 8-11 (m), respectively. Both influent and effluent system pipes are made of Unplasticised Polyvinyl Chloride (UPVC) with diameter equal to 20 mm (DN20). The effluent system

Table 3: Characteristics of the domestic wastewater from DADUKOU district at Chongqing city in China

Parameter	COD (mg/L)	NH_4^+-N (mg/L)	TN (mg/L)	TP (mg/L)	pH
Value	76.5-430	24.31-70.8	28-74.5	1.88-8.27	6.8-7.58

Fig. 3: Batch running cycle mode under start-up phase

of the anoxic MBBR consist of 5 (DN20) UPVC pipes which carry the water to the aerobic MBBR by gravity. The influent and recycle flow was measured by a glass flow meter model LZB-15 (25-250 L/h) for influent flow and glass flow meter model LZB-25 (40-400 L/h) for recycle flow and can be regulated by controlling the manual valves (DN20).

Aeration system consist of 4 fine bubble membrane diffuser (4 aeration dishes 220 mm in diameter) distributed equally on the perimeter of the reactor which are fixed at the height 0.3 m from the bottom of the reactor. Aeration was achieved by using air compressor model ACO-818 (the largest aeration capacity of 300 L/min) connected with the main air distribution pipe (UPVC pipe 25 mm in diameter) which connected each aeration dish with the other. The airflow to the reactor was measured by gas rota meter (model LZB-10WB 5~45 L/min) and regulated with a manual valve. The reactors was operated under the Anoxic/Oxic (An/O) process which must meet stringent TN limits without sludge returning into the system and only an internal recycling was performed from aerobic to anoxic reactor.

Operating procedure: The study was carried out using raw domestic wastewater supplied from the preliminary treatment part in DADUKOU wastewater treatment plant. The quality of wastewater resulting from the various daily uses in DADUKOU district at Chongqing city in China are given in Table 3.

Seeding sludge was obtained from DADUKOU municipal wastewater treatment plant. Firstly the collected sludge was screened with a sieve to remove coarse and inorganic particles, then sludge was aerated for 2 days at room temperature. After that the sludge was mixed with wastewater by the ratio of 2/3 then filled 1/3 of effective volume for reactors by the mixed liquid. By this way the reactors be ready to batch operation mode for 4 weeks. The batch operation was used as start-up for growth of biofilm on carrier elements. After this period, the biofilm appeared on packing elements and MBBRs seemed to be ready for continuous operation. During the batch operation mode the reactors was operated as a Sequencing Batch Moving Bed Biofilm Reactor (SBMBBR) with fill period approximately equal to 6 h for all operation cyclic modes and gas/water ratio equal to 7/1. During the 1st week of operation mode the Mixed Liquor (ML) was continuously aerated in aerobic MBBR and mixing in anoxic MBBR for 18 h and then settled for 4 h after that water discharge with drainage ratio of 100% for 2 h, while during the 2nd, 3rd and 4th week the Mixed Liquor (ML) was continuously aerated in aerobic MBBR and mixing in anoxic MBBR for 14 h and then settled for 4 h after that water discharge with drainage ratio of 100% for 2 h. Figure (3) show the batch daily running cycle during start-up phase. At the end of 4th week the pilot plant was operated under continuous operation mode at Hydraulic Retention Time (HRT) of 6.2 h, with nitrate recycle ratio equal to 100% and gas/water ratio equal to 7/1, getting prepared for main start-up.

At the end of 5th week the pilot plant was operated under continuous operation mode at 3 different HRT (4.95, 6.2 and 8.25 h, respectively) based on the change of wastewater flow rate with gas/water ratio equal to 7/1 and nitrate recycle ratio equal to 100%. During this operation mode the average concentration of DO in aerobic and anoxic MBBRs were 4.49 and 0.16 mg/L, respectively the temperature average values in both anoxic and aerobic MBBRs were 30.7 and 30.9°C, respectively the average value of the total Mixed Liquor Suspended Solids concentration ($MLSS_{Total}$) in both anoxic and aerobic reactors equal to 2896 and 2984.8 mg/L, respectively while PH average values were 7.53 and 7.45, respectively.

Sampling and analysis: Samples were collected from influent and effluent of MBBRs. The analytical techniques used in this study were performed according to the standard methods described in State Environmental Protection Administration (2002). Temperature, Dissolved Oxygen (DO) and PH were measured in each reactor by used Multi parameter Meter (HACH sensionTM156). The Dissolved Oxygen (DO) was tested three times every day in both anoxic and aerobic MBBRs, in the anoxic MBBR the DO was tested in the top, middle and the bottom of the reactor then the average value was used, while in the aerobic MBBR the DO was tested in four points at middle of reactor according to the locations of the aeration dishes then the average value was used. Both the pH and the temperature was tested three times every day in both anoxic and aerobic MBBRs and the tests was done in the middle of the reactors. The samples of COD, ammonium nitrogen (NH_4^+-N), Total Nitrogen (TN) and Total Phosphorous (TP) were measured on alternate days by used HACH DR5000UV Spectrophotometer.

According to Andreottola *et al*. (2000a, b), Jahren *et al*. (2002) and Helness (2007) the assessment of the total Mixed Liquor Suspended Solids concentration on the fixed biomass elements (MLSS) was performed as follows: the attached biomass was removed from the 10bio-carriersbyputtingtheminaflaskwith demineralized water that was placed in an ultrasound bath for 45 min. After that the bio-carriers were rinsed with demineralized water and then the mixed liquid was filtered through 0.45 μm fiber filter and dried at 105°C and weighed. Because of the variability of carriers dimension, the obtained value was referred to the total measured surface of the 10 bio-carriers. MLSS was assessed through the total surface in one cubic meter of reactor.

RESULTS AND DISCUSSION

The continuous up-flow combined cylindrical anoxic/aerobic MBBRs was design and construct to treated 4 m^3/days of domestic wastewater in Chongqing city at Southwest China. The treatment must be satisfactory to meet with grade B of discharge standard of pollutants for municipal wastewater treatment plant in China (GB/T18918-2002) which show in Table 4. Operation and performance data are presented in Table 5 to 7 and shown in Fig. 4 to 12. Before we discuss the results with respect to removal of organic and nutrients, we will explain the mechanism of treatment processes in anoxic/aerobic MBBRs.

The anoxic MBBR was designed to achieve the denitrification processes, while the aerobic MBBR was designed to achieve the nitrification processes. The denitrification processes is very important process in the nitrogen removal by utilizing nitrite and nitrate as electron acceptors, when nitrification rate in aerobic MBBR increases more nitrate enters the anoxic MBBR and as a result more denitrification and subsequently more COD removal is achieved. In the anoxic MBBR some of the phosphate was removed by Denitrifying Phosphate-Accumulating bacteria (DNPAO) which using nitrate as electron acceptor and consumed some of the biodegradable organic matter, there must also be sufficient ammonium available for phosphate denitrification. By this way the anoxic MBBR consumed a part of the biodegradable organic matter (COD) in order to removed nitrate and phosphate. Thus, reducing the pollutants loading rate in the aerobic MBBR and increase overall efficiency of the treatment. In the aerobic MBBR the dissolved oxygen was consume by a competition between heterotrophic (COD removal), autotrophic (nitrification) and Phosphate-Accumulating Organism (PAO), while the biodegradable organic matter (COD) was consume by a competition between heterotrophic and Phosphate-Accumulating Organism (PAO).

Organic carbon (COD) removal: Total COD concentrations of influent, effluent and total removal efficiency versus HRT are shown in Fig. 4 and Table 5, while the average performance of the MBBRs in COD removal are shown in Fig. 5 and Table 6 and 7. The

Table 4: Discharge standard of pollutants for municipal wastewater treatment plant (GB/T18918-2002)

Parameter	COD (mg/L)	BOD_5 (mg/L)	NH_4^+-N (mg/L)	TN (mg/L)	PO_4^{3}-P (mg/L)
Grade A	50	10	5	15	0.5
Grade B	60	20	8	20	1

Table 5: Reactor performance in COD, NH_4^+-N, TN and TP removal at different HRTs in steady state operation

	COD			NH_4^+-N			TN			TP		
HRT (h)	INF. (mg/L)	EFF. (mg/L)	R. (%)	INF. (mg/L)	EFF. (mg/L)	R. (%)	INF. (mg/L)	EFF. (mg/L)	R. (%)	INF. (mg/L)	EFF. (mg/L)	R. (%)
4.95	174.90	51.00	70.84	37.60	10.30	72.61	43.60	28.90	33.72	2.57	1.20	53.31
4.95	359.00	58.70	83.65	32.80	11.30	65.55	38.20	26.60	30.37	3.17	1.16	63.41
4.95	244.00	67.10	72.50	54.10	10.70	80.22	57.60	25.70	55.38	2.89	1.22	57.79
4.95	286.00	63.00	77.97	43.80	9.50	78.31	45.20	23.30	48.45	4.71	1.23	73.89
6.20	276.20	17.10	93.81	26.70	1.10	95.88	31.40	11.40	63.69	2.92	0.28	90.41
6.20	241.70	15.50	93.59	49.50	0.47	99.05	55.80	12.40	77.78	2.83	0.38	86.57
6.20	392.70	13.70	96.51	43.60	0.67	98.46	50.60	13.30	73.72	4.80	0.26	94.58
6.20	163.90	18.50	88.71	45.20	0.53	98.83	48.20	15.20	68.46	3.85	0.31	91.95
8.25	144.60	3.00	97.93	32.70	0.14	99.57	39.10	9.40	75.96	4.95	0.10	97.98
8.25	228.00	4.30	98.11	28.40	0.40	98.59	34.40	11.70	65.99	3.14	0.12	96.18
8.25	276.00	3.10	98.88	53.60	0.10	99.81	60.50	9.60	84.13	3.96	0.15	96.21
8.25	384.10	2.00	99.48	48.70	0.15	99.69	52.70	11.20	78.75	3.14	0.11	96.50

INF.: Total influent; EFF.: Total effluent; R.: Total removal efficiency

Table 6: Average reactor performance in COD, NH_4^+-N, TN and TP removal at different HRTs in steady state operation

	COD			NH_4^+-N			TN			TP		
HRT (h)	Av. INF. (mg/L)	Av. EFF. (mg/L)	Av. R (%)	Av. INF. (mg/L)	Av. EFF. (mg/L)	Av. R (%)	Av. INF. (mg/L)	Av. EFF. (mg/L)	Av. R (%)	Av. INF. (mg/L)	Av. EFF. (mg/L)	Av. R (%)
4.95	265.98	59.95	76.24	42.08	10.45	74.17	46.15	26.13	41.98	3.34	1.20	62.10
6.20	268.63	16.20	93.15	41.25	0.69	98.06	46.50	13.08	70.91	3.60	0.31	90.88
8.25	258.18	3.10	98.60	40.85	0.20	99.42	46.68	10.48	76.21	3.80	0.12	96.72

Av.: Average value; INF.: Total influent; EFF.: Total effluent; R.: Total removal efficiency

Table 7: Standard deviation of reactor performance in COD, NH_4^+-N, TN and TP removal at different HRTs in steady state operation

	COD			NH_4^+-N			TN			TP		
HRT (h)	INF. S.D. (mg/L)	EFF. S.D. (mg/L)	R. S.D. (%)	INF. S.D. (mg/L)	EFF. S.D. (mg/L)	R. S.D. (%)	INF. S.D. (mg/L)	EFF. S.D. (mg/L)	R. S.D. (%)	INF. S.D. (mg/L)	EFF. S.D. (mg/L)	R. S.D. (%)
4.95	77.10	6.88	5.80	9.19	0.75	6.60	8.20	2.32	11.90	0.95	0.03	8.88
6.20	95.12	2.07	3.25	10.01	0.28	1.47	10.55	1.62	6.14	0.92	0.05	3.35
8.25	99.97	0.94	0.72	12.19	0.14	0.56	12.05	1.15	7.61	0.86	0.02	0.85

S.D.: Standard deviation; INF.: Total influent; EFF.: Total effluent; R.: Total removal efficiency

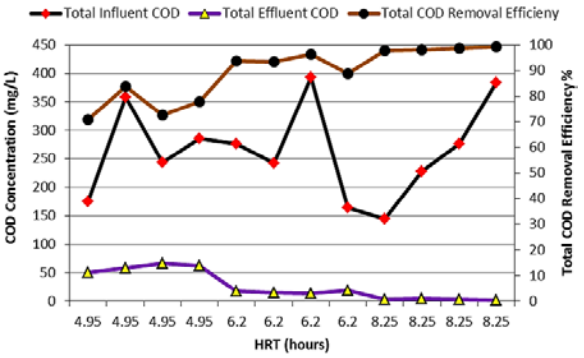

Fig. 4: Profile of COD concentration and removal efficiency variations versus HRT

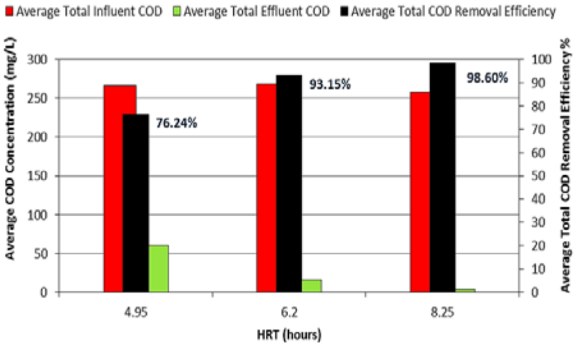

Fig. 5: Profile of average COD concentration and average removal efficiency variations versus HRT

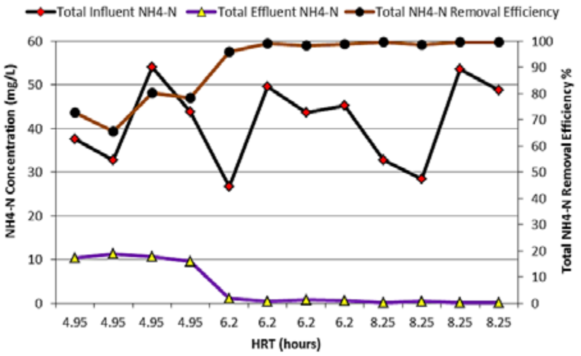

Fig. 6: Profile of NH_4^+-N concentration and removal efficiency variations versus HRT

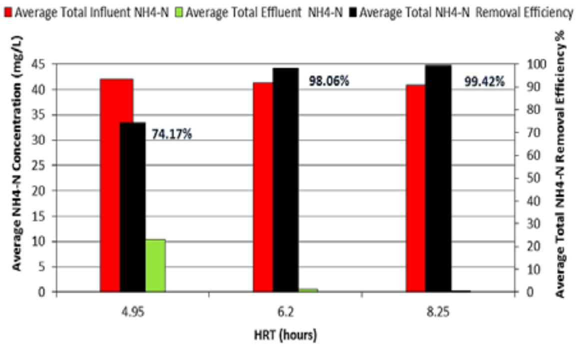

Fig. 7: Profile of average NH_4^+-N concentration and average removal efficiency variations versus HRT

daily fluctuations of COD concentration in the feed were so high that the total effluent COD concentrations steadily decreased to the range 51 to 67 mg/L at HRT of 4.95 h, 13.7-18.5 mg/L at HRT of 6.2 h and 2-4.3 mg/L at HRT of 8.25 h. As HRT was increased from 4.95 to 8.25 h, the average total effluent COD concentrations decreased from 59.95 mg/L (S.D. = 6.88) to 3.1 mg/L (S.D. = 0.94), while the average total removal efficiency increased from 76.24% (S.D. = 5.8) to 98.6% (S.D. = 0.72). At HRT of 4.95 h the average total effluent COD concentration could meet with grade B of discharge standard of pollutants for municipal wastewater treatment plant in China (GB/T18918-2002) (60 mg/L), while at HRT of 6.2 and 8.25 h the average total effluent COD concentration could meet with grade A of discharge standard of pollutants for municipal wastewater treatment plant in China (GB/T18918-2002) (50 mg/L). This meant that HRT did not significantly affect COD removal efficiencies and the anoxic/aerobic MBBRs could tolerate organic-loading impaction.

Ammonium (NH_4^+-N) removal: Total ammonium concentrations of influent, effluent and total removal efficiency versus HRT are shown in Fig. 6 and Table 5, while the average performance of the MBBRs in ammonium removal are shown in Fig. 7 and Table 6 and 7. It seems that the daily ammonium concentration

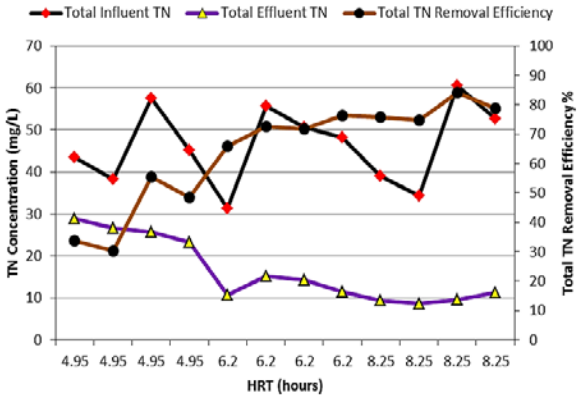

Fig. 8: Profile of TN concentration and removal efficiency variations versus HRT

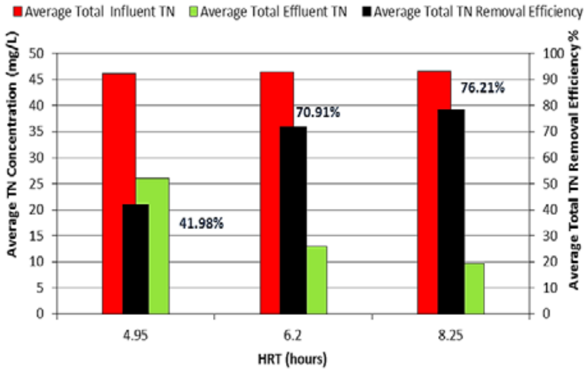

Fig. 9: Profile of average TN concentration and average removal efficiency variations versus HRT

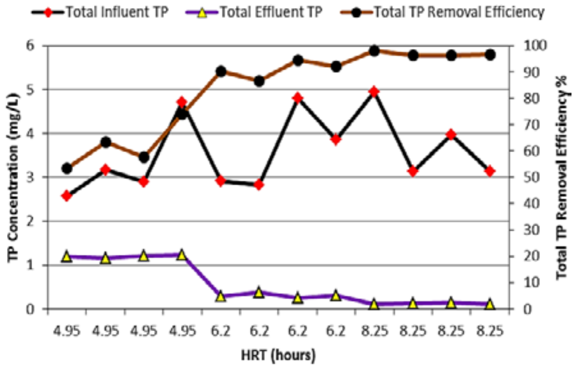

Fig. 10: Profile of TP concentration and removal efficiency variations versus HRT

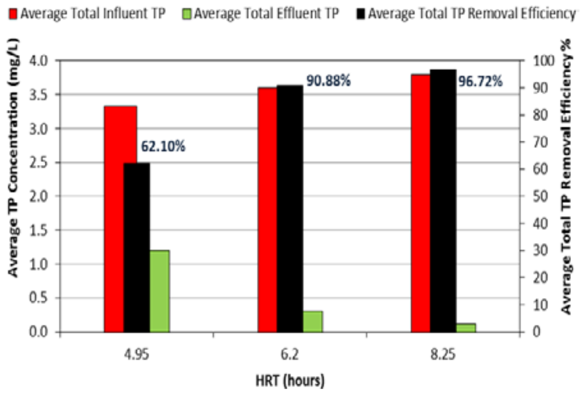

Fig. 11: Profile of average TP concentration and average removal efficiency variations versus HRT

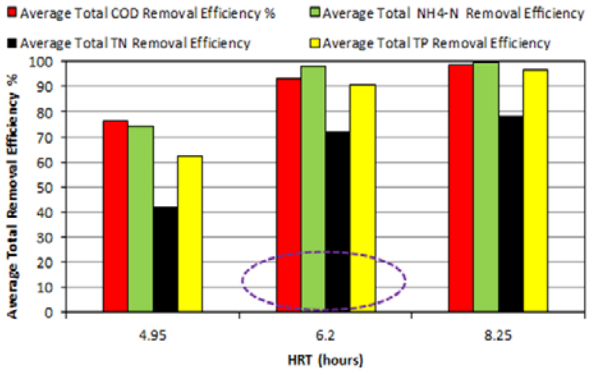

Fig. 12: Average total removal efficiency of COD, NH_4^+-N, TN and TP versus HRT

in the feed fluctuated greatly similar to that for COD. According to Ros *et al*. (1998), the higher concentration of organic matter in the lower HRT lead to a competition between heterotrophic (COD removal) and autotrophic (nitrifiers) organism. Therefore, at HTR of 4.95 h the average total effluent ammonium concentration were 10.45 mg/L (S.D. = 0.75), this value could not comply with grade B of discharge standard of pollutants for municipal wastewater treatment plant in China (GB/T18918-2002) (8 mg/L). As HRT was increased to 6.2 h, the average total effluent ammonium concentrations decreased to 0.69 mg/L (S.D. = 0.28), while the average total removal efficiency increased to 98.06% (S.D. = 1.47). At HRT of 8.25 h, average total effluent ammonium concentrations and average total removal efficiency were 0.2 mg/L (S.D. = 0.14) and 99.42% (S.D. = 0.56), respectively these values are very close to values for HRT of 6.2 h and could meet with grade A of discharge standard of pollutants for municipal wastewater treatment plant in China (GB/T18918-2002) (5 mg/L). According to the results, the HRT significantly affect ammonium removal efficiencies only in range 4.95 to 6.2 h.

Total Nitrogen (TN) removal: The profile of TN concentration and removal efficiency variations versus HRT are shown in Fig. 8 and Table 5, while the average performance of the MBBRs in TN removal are shown in Fig. 9 and Table 6 and 7. As indicated in Fig. 8 and 9 and Table 5 and 6, the influence of HRT on TN removal efficiencies are similar to influence of HRT on ammonium removal efficiencies. As HRT was increased from 4.95 to 6.2 h, the average total effluent TN concentrations decreased from 26.13 mg/L

(S.D. = 2.32) to 12.92 mg/L (S.D. = 2.21), while the average total removal efficiency increased from 41.98% (S.D. = 11.9) to 71.67% (S.D. = 4.31). As HRT was increased to 8.25 h, the average total effluent TN concentrations decreased to 9.73 mg/L (S.D. = 1.06), while the average total removal efficiency increased to 78.39% (S.D. = 4.19). The average total effluent nitrogen at HRT of 6.2 and 8.25 h could meet with grade A of discharge standard of pollutants for municipal wastewater treatment plant in China (GB/T18918-2002) (15 mg/L).

Total Phosphorus (TP) removal: Enhanced Biological Phosphorus Removal (EBPR) was carried out in this study. In the biological phosphorus removal, the phosphorus in the influent wastewater is incorporated into cell biomass, which subsequently is removed from the process as a result of sludge wasting. Phosphorus Accumulating Organisms (PAOs) are encouraged to grow and consume phosphorus in systems that use a reactor configuration that provides PAOs with a competitive advantage over other bacteria (Tchobanoglous *et al*., 2003). Phosphorus removal in biological systems is based on the following observations (Sedlak, 1991):

- Numerous bacteria are capable of storing excess amounts of phosphorus as polyphosphates in their cells.
- Under the anoxic or aerobic conditions, energy is produced by the oxidation of storage products and polyphosphates storage increases within the cell.

The results of TP removal are shown in Fig. 10 and 11 and Table 5 to 7. The results indicate that the average overall phosphorus removal efficiency were increased from 62.1% (S.D. = 8.88) to 96.72% (S.D. = 0.85) as HRT increased from 4.95 to 8.25 h. The anoxic/aerobic MBBRs show acceptable efficiency of TP removal from wastewater except that the average total effluent TP concentration at HRT 4.95 h could not meet with grade B of discharge standard of pollutants for municipal wastewater treatment plant in China (GB/T18918-2002) (1 mg/L). According to the results, the HRT significantly affect TP removal efficiencies only in range 4.95 to 6.2 h. Average total removal efficiency of COD, NH_4^+-N, TN and TP versus HRT are shown in Fig. 12.

CONCLUSION

The results of the examination of a combined cylindrical anoxic/aerobic MBBRs can be summarized as follow:

- The tested anoxic/aerobic MBBRs is a combined system and achieves high COD removal ranging from 76.24 to 98.6% corresponding to HRTs of 4.95 to 8.25 h, from domestic wastewater. The average total effluent COD concentration could meet with grade B of discharge standard of pollutants for municipal wastewater treatment plant in China (GB/T18918-2002) at HRT of 4.95 h, while could meet with grade A of this standard at HRT of 6.25 and 8.25 h.
- These MBBRs was able to remove more than 98.0% of ammonium nitrogen, 71% of total nitrogen and 90% of total phosphorus from influent wastewater at HRT of 6.2 h which is highly preferable to conventional biological nutrient removal.
- The average total effluent of COD, NH_4^+-N, TN and TP concentrations could not meet with grade B of discharge standard of pollutants for municipal wastewater treatment plant in China (GB/T18918-2002) at HRT of 4.95 h, while could meet with grade A of this standard at HRT of 6.25 and 8.25 h.
- In overall, the results obtained showed that the HRT of 6.2 h is optimal for simultaneous organics and nutrients removal.

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