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Simultaneous Organics and Nutrients Removal from Municipal Wastewater in an Up-flow Anaerobic/Aerobic Fixed Bed Reactor

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Abstract: The aim of present study was to design and construct an Up-flow Anaerobic/Aerobic Fixed Bed (UA/AFB) combined reactor in which an anaerobic and aerobic zones could run in a single reactor to study simultaneously carbon and nutrient removal. The UA/AFB developed reactor was made from Plexiglas plate consisting of two main lower anaerobic and upper aerobic parts. A synthetic wastewater was prepared in concentrations which were close to those found in municipal wastewaters. After developing the biofilm on the media, reactor was operated at 5 different HRTs ranging from 5 to 24 h. Samples collected at any HRTs from influent and sampling ports in steady state condition were analyzed according to standard methods for COD, NH_3 , NO^{-}_{3}, PO_4^{-3}, alkalinity and pH. The obtained results showed that the HRT of 7 h was suitable for simultaneous removal of COD, nitrification and denitrification. In this HRT efficiencies are 95.4, 94 and 94.5% for COD removal, nitrification and denitrification, respectively. The reactor did not show good performance in phosphorus removal.

Key words: Municipal wastewater, carbon oxidation, nutrient removal, combined reactor

INTRODUCTION

The most important adverse environmental impacts associated with improper discharge of municipal wastewater having significant amounts of organic matter (COD), nitrogen (N) and phosphorous (P) include promotion of Eutrophication, toxicity to aquatic organisms and depletion of dissolved oxygen receiving streams[1,2]. Due to these adverse impacts, completed treatment of municipal wastewater before discharge has been increasingly needed.

Currently, the most of municipal wastewaters are treated in an activated sludge process to meet the standards for direct discharge[3]. Although, the new discharge standards for nitrogen and phosphorous will lead to the upgrading of the existing wastewater treatment plants and to the conception of new intensive advanced technologies[4]. In recent years there have been many researchers considering the complete treatment of wastewater but they have all more or less dealt with different combination of biological process in separated reactors[5]. Biofilm processes in particular submerged fixed bed reactors developed during recent years are a good alternative for improved wastewater treatment[5].

Therefore, the aim of present investigation was to design and construct an Up-flow Anaerobic/Aerobic Fixed Bed (UA/AFB) combined reactor in which an anaerobic and aerobic zones could run in a single reactor to study simultaneously carbon and nutrient removal.

MATERIALS AND METHODS

The experimental set up: The UA/AFB reactor as showed in Fig. 1, was made from plexiglas plate consisting of two main anaerobic and aerobic parts separated with a distributing perforated plate. The reactor was filled with corrugated plastic tubes as a media. Sampling ports were provided in each part for sample collection. Table 1 lists the dimensions of the investigated UA/AFB reactor.

Operating conditions: Synthetic wastewater was prepared using glucose as a source of carbon, ammonium chloride as a nitrogen source and sodium nitrate as a nitrate source, to investigate denitrification in the reactor, in concentrations which were close to those found in municipal wastewaters. The average characteristics of synthetic wastewater are shown in Table 2. Reactor was operated in an up-flow mode.

To develop biofilm on the media, reactor was inoculated with 2 L of thickened activated sludge from a local wastewater treatment plant. The biofilm development was achieved using a medium 3 times as concentrated as

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Table 1: Dimensions of the studied UA/AFB combined reactor

Parameter	Anaerobic zone	Aerobic zone	Overall
Media	Corrugated tubes (7×15 mm)	Corrugated tubes (7×15 mm)	Corrugated tubes
Media specific surface (m^2 m^{-3})	640.00	640.00	640.00
Bed height (cm)	40.00	60.00	100.00
Bed volume (L)	6.20	7.80	14.00
Total media surface (m^2)	3.97	4.99	8.96
Internal Diameter (cm)	13.50	13.50	13.50
Flow direction	Up-flow	Up-flow	Up-flow
Zones position	lower	upper	-------

Table 2: Characteristics of synthetic wastewater

Parameter	Value*
COD	365.0
NH_3 - N	36.0
NO_3^--N	24.0
PO_4^{-3}-P	8.0
Alk.(as $CaCO_3$)	230.0
pH	7.4

*All parameters in mg L^{-1} except pH

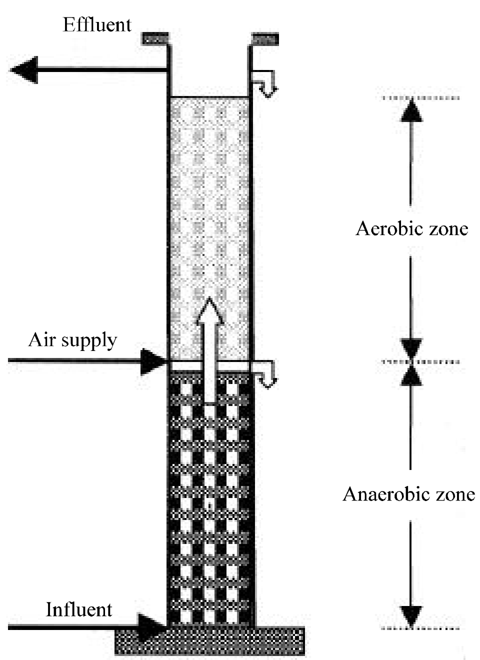

Fig. 1: Schematic figure of UA/AFB experimental combined reactor

the characteristics listed in Table 2 and running the reactor first for 10 days in a batch mode and then over to the continuous mode for 5 days at Hydraulic Retention Time (HRT) of 24 h and a 2 times concentration of the synthetic wastewater.

After biofilm formation, reactor was run at different HRTs based on wastewater flow rate change with the stable COD, N and P concentration in influent. At any set of the experiment HRT, reactor was monitored to achieve the steady state condition in effluent. When the effluent COD from any parts of reactor did not vary significantly for five consecutive samples, a steady state condition in COD removal was assumed to have been achieved.

Sampling and analysis: Grab samples were collected from influent and sampling ports showed in Fig. 1. Samples were analyzed for COD (5220 C. Titrimetric method), total ammonia nitrogen (4500-NH_3 A. Titrimetric method), nitrate nitrogen (4500-NO_3^- B. UV Spectrophotometric screening) and total phosphorous (4500-P C. Vanadomolybdophosphoric Acid colorimetric method) according to standard methods[6]. All parameters were measured on alternate days except for pH, DO and alkalinity witch were monitored daily. DO was analyzed by an YSI DO meter, pH by a pH meter and alkalinity according to standard methods[6].

The reactor performance for nitrogen removal was evaluated by the apparent volumetric of nitrification and denitrification rate (R_N, g N m^{-3}/day) in each part of reactor[4]:

$$R = (S_0\text{-}S)/\ HRT$$

Where, S_0 and S are the initial and effluent substrate concentration as mg L^{-1} calculated based on overall bed volume.

RESULTS AND DISCUSSION

COD removal: Figure 2 shows variation of the effluent COD and COD removal efficiency to achieve the steady sate condition in operation during start-up. As indicated, after passing 17 days from starting up, reactor efficiency in COD removal was stable in 94%. It present that the suitable biofilm have been formed.

Table 3 indicates average values of COD removal efficiency at different organic loading rate corresponding to HRTs of 5 to 24 h.

Figure 3 gives the overall and separated COD removal in the reactor at different HRTs. According to the Fig. 3,

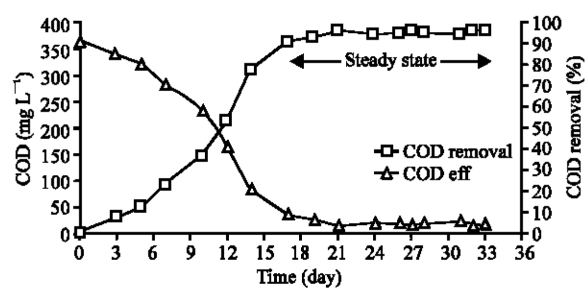

Fig. 2: Profile of COD removal and effluent concentration during start-up reactor

Table 3: Reactor performance in COD removal at different HRTs in steady state operation

		COD loading (kg m^{-3}/ day)			COD removal (%)		
HRT(h)	Q (L h^{-1})	Overall	Anaerobic	Aerobic	Anaerobic	Aerobic	Overall
5	2.80	1.752	3.956	1.730	45	89	94.0
7	2.00	1.251	2.826	1.033	54	90	95.4
10	1.40	0.876	1.978	0.645	59	92	96.7
15	0.94	0.588	1.328	0.369	65	93	97.6
24	0.21	0.131	0.297	0.061	74	91	97.7

Table 4: Performance of the reactor in ammonia nitrogen removal at different HRT

		NH_3-N loading (g Nm^{-3}/day)	Nitrification (%)		
HRT(h)	Q (L h^{-1})	Overall	Anaerobic	Aerobic	Overall
5	2.80	172.8	8.3	85.0	86.0
7	2.00	123.4	10.5	93.3	94.0
10	1.40	86.4	11.1	94.7	95.3
15	0.94	58.0	11.7	95.0	95.8
24	0.21	13.0	13.9	95.3	96.0

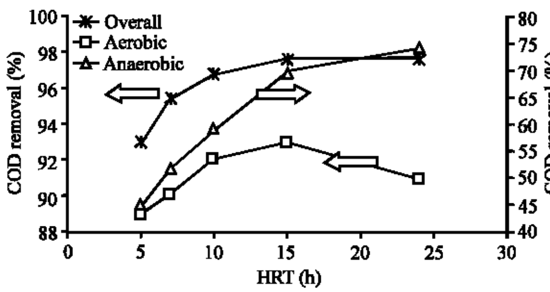

Fig. 3: COD reduction profile in overall and different parts of reactor versus HRT

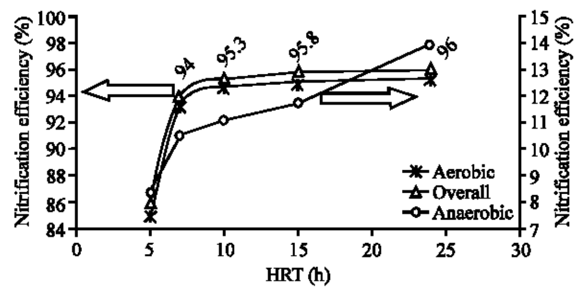

Fig. 4: Profile of nitrification efficiency variations versus HRT

most of COD removal occurred in the aerobic part of the reactor. This was expected, because aerobic bacteria are dominate in this part having higher organic biodegradation rate. As HRT was increased in range of 5 to 24 h, the overall efficiency of COD removal increased. It seems that HRT of 5 h in which COD reduced to 94%, could meet discharge requirements in Iran. According to Iran Environmental Protection Agency standards, monthly average of effluent COD to discharge into surface water is 60 mg L^{-1}.

The relationship between COD loading rate and COD removal efficiency was linear with R^2 of 0.97. Westerman *et al.*[7] similarly obtained a linear relationship between COD loading rate and its removal in an up-flow aerated filter.

Nitrification: Ammonia nitrogen removal (Nitrification) was studied simultaneously with COD removal in the developed reactor. Table 4 shows NH_3 loading and nitrification efficiency data in overall, anaerobic and aerobic parts of the reactor. Figure 5 shows these variations graphically. As indicated in Fig. 5 and Table 3, percent of ammonia nitrogen removal in the anaerobic is very low, in which the removed ammonia have been consumed for cell synthesis. In the other word, nitrification only occurred in aerobic zone of the reactor. Table 4 shows that as the HRT have been increased in range of 5 to 24 h, nitrification increased from 86 to 96%.

Figure 4 indicates that HRT of 7 h is optimum for sufficient nitrification in the tested reactor in witch nitrification efficiency was 94%. In this HRT, ratio of COD removal rate to nitrification rate was close to 10. According to Ros *et al.*[5], the higher concentration of organic matter in the lower HRT lead to a competition for oxygen in biofilm between heterotrophic (COD removal) and autotrophic (nitrifiers) organism.

In Fig. 4 the nitrification efficiency have been plotted versus HRTs of between 5 to 24 h. It can be seen that while the ammonia concentration was consistent at all HRTs, nitrification efficiency varied at different HRT. A possible explanation of this situation is the difference in COD removal efficiency of anaerobic zone of the reactor and in turns, organic loading on aerobic zone in where nitrification occurred. As HRT was increased, COD removal efficiency in anaerobic zone of the reactor increased and COD loading on aerobic zone decreased that was resulted in increasing nitrification efficiency.

Figure 5 shows the profile of nitrification rate variations versus ammonia nitrogen loading rate. As indicated, nitrification rate have increased with increasing

Table 5: Reactor performance in nitrate removal at different HRTs in steady state operation

		NO^{-3}-N loading ($kg\ m^{-3}$/day)	Denitrification (%)		
HRT(h)	Q ($L\ h^{-1}$)	Overall	Overall	Anaerobic	Aerobic
5	2.80	115.20	95.0	95.0	0
7	2.00	82.30	94.5	94.5	0
10	1.40	57.60	92.0	92.0	0
15	0.94	38.70	91.0	90.0	0
24	0.21	8.64	91.0	91.5	0

Table 6: Reactor performance in phosphorus removal at different HRTs in steady state operation

		PO_4^{-3}-P loading ($kg\ m^{-3}$/day)	PO_4^{-3}-P removal (%)		
HRT(h)	Q ($L\ h^{-1}$)	Overall	Overall	Anaerobic	Aerobic
5	2.80	38.4	12.0	5.5	10.9
7	2.00	27.4	12.1	6.4	11.1
10	1.40	19.2	12.5	7.4	11.7
15	0.94	12.9	12.6	8.2	11.9
24	0.21	2.9	12.6	8.9	11.7

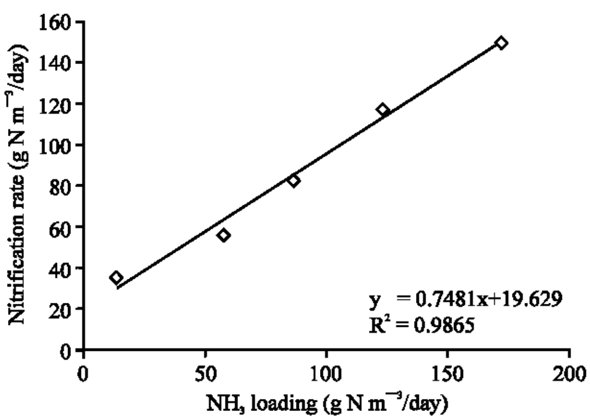

Fig. 5: Relation between ammonia loading and nitrification rate

ammonia loading varying between 148.8 to 34.6 g NH_3-N m^{-3}/day. The results suggest that the nitrification may was inhibited by substrate (ammonia) concentration so that increasing of the ammonia loading have leaded to increasing the nitrification rate.

Denitrification: To study the ability of the reactor in removal of ammonia nitrogen (Denitrification), wastewater having nitrate concentration of 24 mg L^{-1} was pumped into the anaerobic part of the system. The COD to NO_3-N ratio in the influent wastewater was around 15. Table 5 shows the denitrification efficiency in overall and anaerobic part of reactor at different HRT. It should be emphasis that denitrification was not occurred in aerobic zone that is according to denitrification theory[3].

As indicated in Fig. 6, increasing HRT was resulted in decreasing denitrification efficiency. Maximum denitrification efficiency of 94% obtained in HRT of 5 h

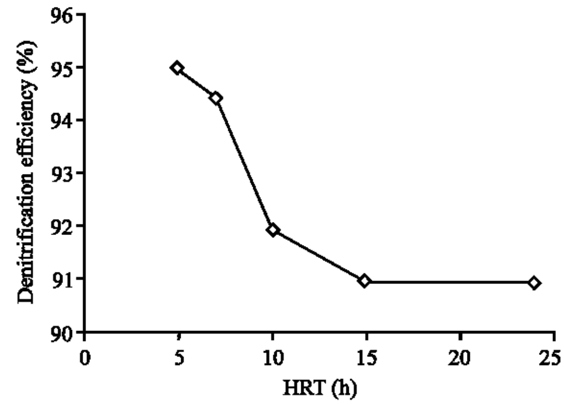

Fig. 6: Variation of denitrification efficiency versus HRT

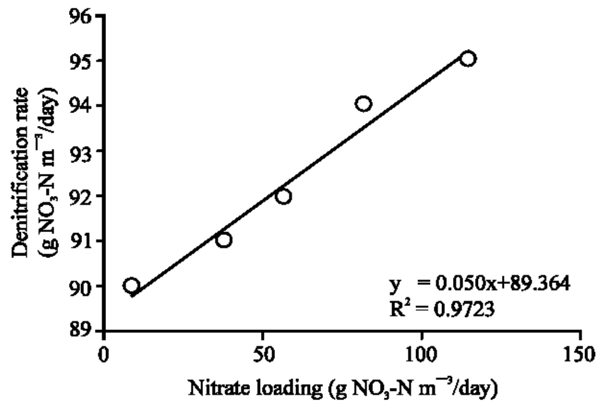

Fig. 7: Relation between nitrate loading and denitrification rate

and minimum of that was 91% in HRT more than 15 h. The higher denitrification efficiency obtained in lower can be explained due to the higher anaerobic biodegradation products favorable for denitrifirs such as acetate in the lower anaerobic HRT that is the most efficient substrate for denitrification. Ros *et al.*[5] showed that acetic acid which is transformed to acetate, is dominating product of acidification in low HRT in the anaerobic degradation of organics.

Figure 7 indicates a linear relation between NO_3-N loading and denitrification rate with R^2 0.97.

Phosphorus removal: The results obtained from the tested reactor for phosphorus removal have been shown in Table 6. The overall phosphorus removal efficiency was low and maximum removal percent occurred in HRT of 24 h. The results indicate that phosphorus removal is related to cell synthesis and as expected, the reactor did not show acceptable efficiency from wastewater. Increased phosphorus removal could be obtained by chemical precipitation or possibly by adding a biological suspended growth system to promote biological luxury uptake of phosphorus as described by Goncalves *et al.*[8].

CONCLUSION

The results of the examination of a new Up-flow Anaerobic/Aerobic Fixed Bed reactor can be summarized as follow:

1. The tested UA/AFB reactor is a compacted system and achieves high COD removal ranging from 94 to 97.7% corresponding to HRTs of 5 to 24 h, from municipal wastewater.
2. This reactor was able to remove more than 94% of ammonia nitrogen from influent wastewater in HRT of 7 h which is highly preferable to conventional biological nutrient removal.
3. As expected, the reactor did not show good performance in phosphorus removal so, to achieve more efficiency combining a biological or chemical process is require.
4. In overall, the results obtained showed that the HRT of 7 h is optimal for simultaneous COD removal, nitrification and denitrification. In this HRT efficiencies are 95.4, 94 and 94.5% for COD removal, nitrification and denitrification, respectively.

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