

Research Article

Effect of Hydraulic Retention Time and Wastewater Temperature on Treatment Efficiency of Upflow Anaerobic Filter Treating Campus Domestic Wastewater

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Abstract: The study examined the removal efficiency of upflow anaerobic filter reactor fed continuously with campus domestic wastewater at different hydraulic retention time and wastewater temperature. The reactor was filled with non woven filter materials and operated at hydraulic retention time ranging from 1 to 6 days and wastewater temperature ranging from 20 to 30°C. At that operating condition, the result revealed no significant difference for Carbonaceous (COD) and nutrients materials except there was significant production of gas. The result revealed that increase in HRT and wastewater temperature improves removal performance of the reactor. The overall reactor removal efficiency for COD, TN, NH₄⁺-N, NO₃-N and TP concentration were 51, 22, 21, 28 and 10% and 61, 35, 37, 49 and 27% in the anaerobic and anoxic columns, respectively. The experimental system was capable of instantaneous removal of the carbonaceous, nitrogenous and phosphorous compounds.

Keywords: Anaerobic and anoxic column, carbonaceous, non woven filter materials, nutrients

INTRODUCTION

University campus is one of the most common institutions all over the entire world that uses considerable amount of fresh water and generates substantial amount of wastewater. Although the wastewaters from this institution is characterized by low content of nutrients and pathogens (Otterpohl *et al.*, 1999; Jefferson *et al.*, 1999; Eriksson *et al.*, 2002), it can be potentially very polluting and contributes to aquatic and terrestrial environmental pollution. Therefore, treatment of wastewaters from this institution nowadays receives special attention.

Anaerobic treatment process is an attractive process for the treatment of low strength campus domestic wastewater as it requires less energy for its operation and less excess sludge is produced as compared to the aerobic process. Over the last few decades, several types of anaerobic process have been used to treat wastewaters arising from domestic or industrial. Among them includes the upflow anaerobic filter (Ladu *et al.*, 2012b), anaerobic hybrid (Thanh Tran *et al.*, 2003), Upflow Anaerobic Sludge Blanket (UASB) (Behling *et al.*, 1997; Barbosa and Sant'Anna Jr., 1989), the Anaerobic Sequencing Batch Reactor (AnSBR) (Sung and Dague, 1995; Ng, 1989), Anaerobic Baffled Reactor (ABR) (Langenhoff and Stucky, 2000; Bodik *et al.*, 2003), Anaerobic Migrating

Blanket Reactor (AMBR) (Angenent and Sung, 2001) and Expanded Granular Sludge Bed (EGSB) (Van der Last and Lettinga, 1992; Seghezze, 1997).

The upflow anaerobic filter is one of the earliest device designs with well defined operational characteristics (Henze and Harremoes, 1983). It's not as complex as other anaerobic reactors and does not require the formation of a granular sludge, a prerequisite for upflow sludge blanket digester (Ahn and Forster, 2000a). In general, the anaerobic treatment process (particularly UAF) have an advantages in anaerobic treatment systems (Ladu *et al.*, 2012a) and has gained momentum simply because its process is simple, low running cost and doesn't require complex professional management. Besides, the process has an advantage by producing biogas, which can be used as source of energy. Hence, this particular paper was conducted with an aim of evaluating the effect of Hydraulic Retention Time (HRT) and wastewater temperature on the overall performance of the Upflow Anaerobic Filter (UAF) treating campus domestic wastewater in the Southeast University campus of Taihu lake environmental program.

MATERIALS AND METHODS

Experimental set-up: This research was carried out in Southeast university campus of Taihu Lake

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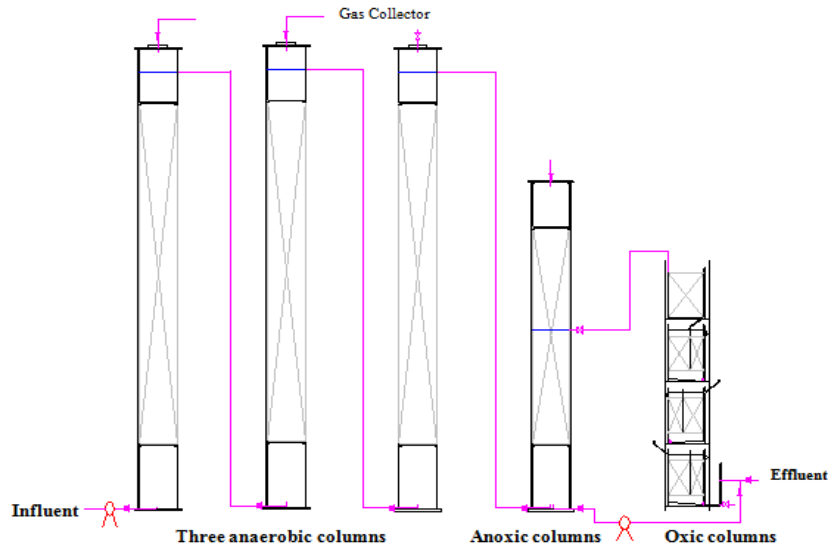


Fig. 1: Schematic process flow UAF reactor columns

Table 1: Composition of the studied area domestic raw wastewater

Parameter	Min.	Max.	Avg.
COD (mg/L)	76	418	197
NH ₄ ⁺ -N (mg/L)	10.9	44.2	27.1
NO ₃ ⁻ -N (mg/L)	0.1	7.7	2.4
TP	1.1	7.9	3.6
pH	7.7	8.2	7.9

Min.: Minimum; Max.: Maximum; Avg.: Average

environmental program, in Wuxi, Jiangsu Province. The experimental system comprised of a regulating tank (influent tank), two submersible pumps and UAF bioreactor system. The schematic diagram of the experimental set-up (UAF) is shown in Fig. 1. The upflow anaerobic filter systems have four columns and were constructed of Polyvinylchloride (PVC), with a total capacity of 300 L. The first three columns were typically operated as an anaerobic zone and fourth column contained an anoxic zone. The reactors were filled to height of 2.3 m with a non-woven fabric filter materials of length 2500 mm, width of 50 mm, surface area of 150 m²/m³ and with porosity of 97%. The anaerobic filter reactors have an effective volume of 90 L for each anaerobic columns and 60 L for anoxic column, respectively. The influents were pumped from same fed tank to the bottom of the columns by the help of long pump (model BT100). The effluent samples of every reactor columns were collected at the sampling and effluent discharge ports in separate bottles after every 2 days and stored in refrigerator at 5°C before experimental tests in the laboratory.

Wastewater for the experiment: Raw wastewater from a campus main manhole was pumped into a storing tank for sedimentation and then fed into the reactor. The Upflow anaerobic filter reactor was inoculated with sludge obtained from Wuxi municipal

sewage treatment plant which utilizes a typical change in the environmental state condition (anaerobic, anoxic, or aerobic) to treat municipal wastewater. COD infiltrated ranges between 165 and 411 mg/L. The raw domestic wastewater composition is shown in Table 1. The reactor was operated continuously for 30 days as the start-up period until the reactor performance was stable (acclimatized).

Estimation of parameters:

Hydraulic retention time: The Hydraulic Retention Time (HRT), given in days, is expressed as:

$$HRT = \frac{1}{VHL} \tag{1}$$

This gives:

$$HRT = \frac{V}{Q} \tag{2}$$

where,

VHL = Volumetric hydraulic load (m³/ (m³·d)

Q = Flow rate (m³/d)

V = Total volume of the reactor (m³)

From Eq. (2), the required reactor volume can be easily obtained.

Efficiency of the reactor: The removal of COD in the system (UAF) refers to the difference between the influent and the effluent COD, hence the COD removal percentage was calculated and expressed by:

$$COD(\%) = \frac{COD_{inf} - COD_{eff}}{COD_{inf}} \times 100 \tag{3}$$

Table 2: Test parameters and methods

Parameters	Methods
COD	Potassium dichromate (GB 11914-89)
TN	On the persulfate UV spectrophotometer (GB 11894-89)
NH ₄ ⁺ -N	Nessler's reagent (GB7479-87)
NO ₃ ⁻ -N	Sulfamate UV spectrophotometer (GB7480-87)
TP	UV spectrophotometer (GB 11894-89)

where,

COD_{inf} = The influent COD concentration (mg/L)

COD_{eff} = The effluent COD concentration (mg/L)

This equation is also applied for calculating the efficiency of the reactors in regards to the nitrogenous and total phosphorus nutrients.

Analytical procedures: The following parameters and methods of testing shown in Table 2 were used for this study. All the analyses were carried out in accordance with the Chinese standard methods for determination of municipal sludge in wastewater treatment plant (s) (CJT 221-2005). The samples were filtered through a 0.45-µm membrane filter before experimental analysis. The filtered sample preserved frozen for nitrates, ammonium nitrogen determination and other unfiltered was use for TN and TP determination, whereas the other sample was then preserved with H₂SO₄. The sample preserved with acid was used for COD tests; acid added was about 1% of sample volume to be preserved. The influent and the effluent COD, TN, NH₄⁺-N, NO₃⁻-N and TP were measured according to the standard methods recommended by US Environmental Protection Agency (APHA, 1999). Temperature and pH was measured by dissolved oxygen meter. Gas production was measured by wet gas meter. The flow rate was controlled by a valve and incessantly regulated by the help of a pump.

RESULTS AND DISCUSSION

Evaluate the average removal rate of COD, TN, NH₄, NO₃ and TP at different HRT and different wastewater temperature: The Upflow Anaerobic Filter (UAF) system was operated subsequently at HRTs of, respectively, 1, 2, 3, 4 and 6 days and fluctuating wastewater temperature. The first two to three weeks of operation was considered as a start-up period, until the reactor acclimatized to the new HRT and stable temperature. The effect of HRT and temperature on COD, TN, NH₄⁺-N, NO₃⁻-N and TP removal rate was examined (Table and Fig. 3 to 7).

COD removal: The overall concentrations of COD in the influent and effluent of UAF during the experimental operations were 192.8 and 65.2 mg/L, respectively (Table 3 and Fig. 2).

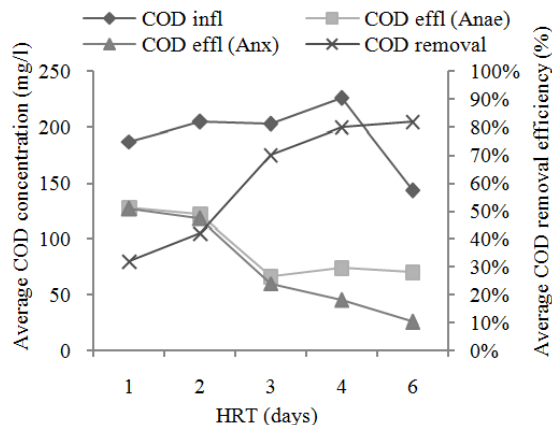


Fig. 2: Average COD concentrations and removal at different HRT and columns

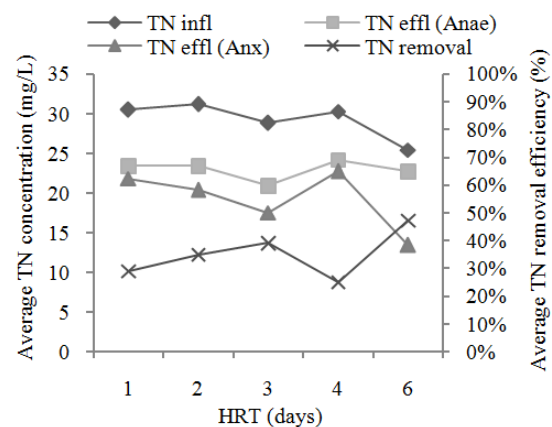


Fig. 3: Average TN concentrations and removal at different HRT and columns

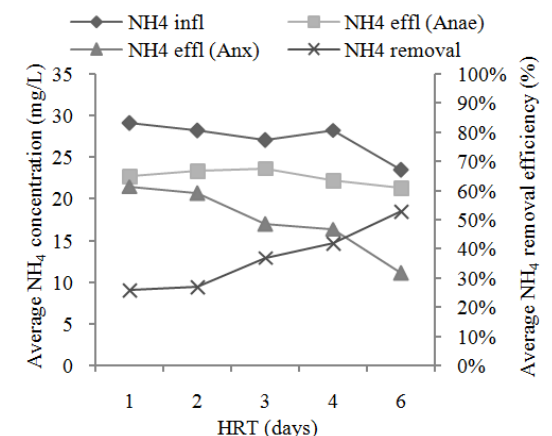


Fig. 4: Average NH₄⁺-N concentrations and removal at different HRT and columns

Total nitrogen (TN (removal): The average concentrations of TN in the influent and effluent of UAF during the experimental operations were 29.3 and 18.3 mg/L, respectively (Table 4 and Fig. 3).

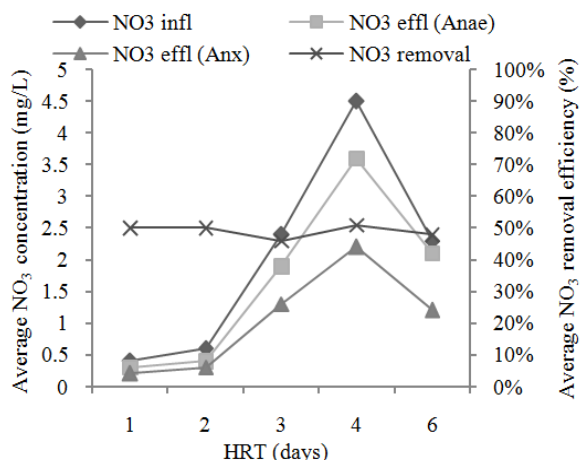


Fig. 5: Average NO₃ concentrations and removal at different HRT and columns

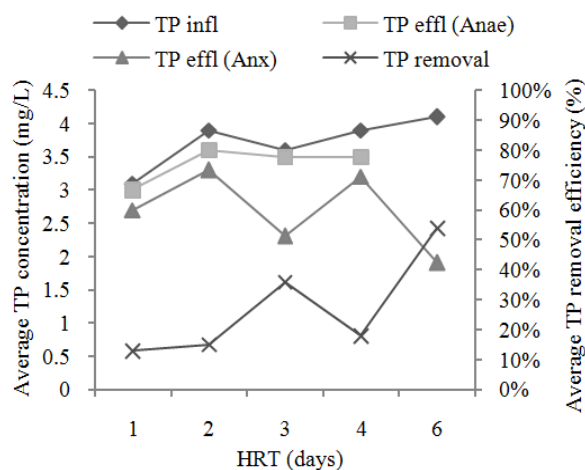


Fig. 6: Average TP concentrations and removal at different HRT and columns

Ammonium nitrogen (NH₄⁺-N): The average concentrations of NH₄⁺-N in the influent and effluent of

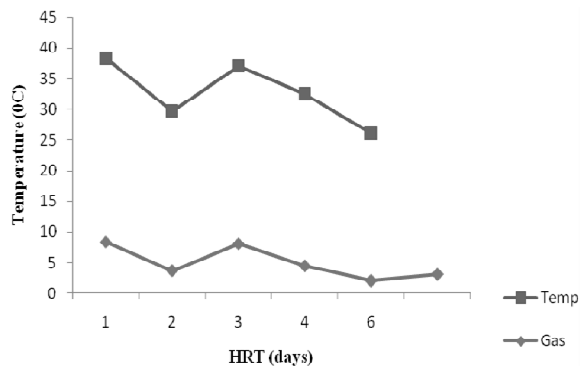


Fig. 7: Relationship between gas and temperature at different HRT

UAF during the experimental operations were 27.1 and 16.1 mg/L, respectively (Table 5 and Fig. 4).

Nitrate nitrogen (NO₃⁻-N): The average concentrations of NO₃⁻-N in the influent and effluent of UAF during the experimental operations were 2.04 and 1.6 mg/L, respectively (Table 6 and Fig. 5).

Total Phosphorus (TP): The average concentrations of TP in the influent and effluent of UAF during the experimental operations were 3.6 and 2.5 mg/L, respectively (Table 7 and Fig. 6).

pH result: The pH fluctuations of the influent and effluent in the UAF reactor were monitored over time and the average pH in the influent and effluent during the experimental operations were 7.7 and 7.9 mg/L, respectively.

Gas production: The average gas produced at different HRT, temperature and columns is shown in Table 8 and Fig. 7. As the system stabilized, the average gas produced varied between 2.1 to 8.4 L/d in the whole experimental operations, respectively.

Table 3: The average removal rate of COD with time at different HRT and temperature

HRT	Temp (°C)	Influent (mg/L)	Effluent (An) (mg/L)	Effluent (Anx) (mg/L)	Removal rate (An) (%)	Removal rate (Anx) (%)
1	20	187	128	127	32	32
2	25	205	122	118	40	42
3	27	203	66	60	67	70
4	31	226	74	45	67	80
6	30	143	70	26	51	82

HRT: Hydraulic retention time; An: Anaerobic column; Anx: Anoxic column

Table 4: The average removal rate of TN with time at different HRT and temperature

HRT	Temp (°C)	Influent (mg/L)	Effluent (An) (mg/L)	Effluent (Anx) (mg/L)	Removal rate (An) (%)	Removal rate (Anx) (%)
1	20	30.5	23.4	21.8	23	29
2	25	31.2	23.4	20.4	25	35
3	27	28.8	20.9	17.5	27	39.24
4	31	30.3	24.2	22.7	25	25.08
6	30	25.4	22.7	13.4	11	47.24

HRT: Hydraulic retention time; An: Anaerobic column; Anx: Anoxic column

Table 5: The average removal rate of NH₄⁺-N with time at different HRT and temperature

NH ₄ ⁺ -N (mg/L)						
HRT	Temp (°C)	Influent (mg/L)	Effluent (An) (mg/L)	Effluent (Anx) (mg/L)	Removal rate (An) (%)	Removal rate (Anx) (%)
1	20	29.1	22.7	21.5	22	26
2	25	28.2	23.4	20.7	17	27
3	27	27.1	23.7	17.0	13	37
4	31	28.3	22.2	16.4	42	42
6	30	23.5	21.3	11.1	9	53

HRT: Hydraulic retention time; An: Anaerobic column; Anx: Anoxic column

Table 6: The average removal rate of NO₃ with time at different HRT and temperature

NO ₃ -N						
HRT	Temp (°C)	Influent (mg/L)	Effluent (An) (mg/L)	Effluent (Anx) (mg/L)	Removal rate (An) (%)	Removal rate (Anx) (%)
1	20	0.4	0.3	0.2	25	50
2	25	0.6	0.4	0.3	33	50
3	27	2.4	1.9	1.3	21	46
4	31	4.5	3.6	2.2	51	51
6	30	2.3	2.1	1.2	8.7	48

HRT: Hydraulic retention time; An: Anaerobic column; Anx: Anoxic column

Table 7: The average removal rate of TP with time at different HRT and temperature

TP (mg/L)						
HRT	Temp (°C)	Influent (mg/L)	Effluent (An) (mg/L)	Effluent (Anx) (mg/L)	Removal rate (An) (%)	Removal rate (Anx) (%)
1	20	3.1	3	2.7	3	13
2	25	3.9	3.6	3.3	8	15
3	27	3.6	3.5	2.3	3	36
4	31	3.9	3.5	3.2	10	18
6	30	4.1	2.7	1.9	34	54

HRT: Hydraulic retention time; An: Anaerobic column; Anx: Anoxic column

Table 8: Average gas produced at different HRT, temperature and columns

Gas produced (L/d)					
HRT	Temp	An ₁	An ₂	An ₃	Total (L/d)
1	30	1.190	5.220	2.610	8.370
2	26	1.180	1.590	0.950	3.710
3	29	5.465	1.750	0.885	8.100
4	28	2.365	1.766	0.345	4.476
6	24	0.564	1.447	0.060	2.072
6	26	0.235	3.245	0.278	3.109

An₁, An₂, An₃ refers to Anaerobic column 1, 2 and 3

Discussion: The results showed in table (Table and Fig. 3 to 7) illustrated the effect of HRT on the removal of organic Carbon (COD) and nutrients. The overall results demonstrated that increasing the HRT from 1 to 6 days significantly improves the removal performances. At an HRT of 4 and 6 days, the reactor removes 80 and 82% of COD, which is significantly higher than that at an HRT of 1 and 2 days. However, the removal of COD does not significantly decline when decreasing the HRT from 3 to 2 days and to 1 day. At an HRT of 3, 2 and 1 days, the reactor removes 70, 42 and 32% of the COD, respectively. It can also be notice that, the sudden increase in influent COD concentrations improved the treatment performance of percent COD efficiencies. The results coincided with the study by Thanh Tran *et al.* (2003) and Elmitwalli *et al.* (2002). As compared to the removal efficiency in the anoxic column, the removal performance of anaerobic column in terms of percent COD is low. There was no significant difference found in the

removal of nutrients in the reactor system between different HRTs and temperature. The results indicated that campus domestic wastewater had limited amount of nutrients which was mainly in particulate form (80-90%). The concentration of phosphorus in the effluent was almost similar to that of the influent and revealed poor removal performance of TP at the anaerobic columns as compared to the anoxic column. Generally, the removal of nitrogenous compound in the anaerobic column is low as compared to the anoxic column. The reactor removal performance of COD, TN, NH₄⁺-N, NO₃-N and TP concentration in the anaerobic and anoxic columns were 51, 22, 21, 28 and 10% respectively and 61, 35, 37, 49 and 27%, respectively. At longer HRT, the removal of nitrogenous compounds was low in the anaerobic column and this can be attributed to hydrolysis of particulate nutrients respectively (Elmitwalli and Ralf, 2007). The results of several studies indicated that the nitrifying bacteria mostly grow well at temperature of 25 to 30°C. When the temperature is less than 15°C, the activity of nitrifying bacteria significantly reduces the nitrification rate. In this study, the reactor temperature operated within the standard temperature and hence, there was biological removal of nutrients by the reactor.

Monitoring of pH in the anaerobic reactor is crucial and can be helpful in detecting system abnormalities (Graef and Andrew, 1974). In this study, the pH of the treated domestic wastewater (effluent) was in the range of 7.7-7.9, indicating satisfactory condition of the reactor. According to literatures, pH values less than

6.8 and greater than 8.3 would cause souring of the reactor in the process of anaerobic digestion (Stronach *et al.*, 1986; Wheatley, 1991). Generally, the pH throughout the UAF effluent remained stable despite increase in HRTs.

Temperature is one of the key factors affecting the anaerobic digestion process and gas production. The amount of gas produced at different HRT, temperature and columns is shown in Table 8. The amount of gas produced was depended on the influent COD concentrations, HRT and wastewater temperature. The daily gas production varied between 2.1-8.4 L/d with an average of 4.9 L/d. As can be seen from the table, gas production is greatly affected by temperature. The result demonstrated that temperature greatly influence the gas production. Whenever the temperature and influent COD concentration has increased significantly, gas production almost simultaneously increases significantly. More gas production has been produced by column 2 (An₂) than in column 1 (An₁) and 3 (An₃). Because An₁ is the beginning of digestion process where organic matters are transformed into acid but in An₂, there is more matrix substrate utilization and increase in methanogenic bacteria activity. In An₃, the temperature might have also reduced as compared to An₂.

Generally, the experimental system was capable of instantaneous removal of the carbonaceous, nitrogenous and phosphorous compounds as well as gas production.

CONCLUSION

In this study, we investigated the influences of the hydraulic retention time and wastewater temperature fluctuations for a typical anaerobic and anoxic filter process to treat the campus domestic wastewater. The removal performance illustrated that, UAF reactor was affected by changing HRT and wastewater temperature. The optimum removal efficiency was obtained for HRT 3 days at an average temperature of 30°C. The pH throughout the UAF effluent remained stable despite increase or decrease in HRTs. The gas produced increased with increase in HRT and temperature although other COD concentration in the influent also interferes. Hence, the application of UAF reactor in the campus domestic wastewater can significantly plays an important role for the development of effective and feasible concepts for all types of wastewater treatment process.

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