SEASONAL PERFORMANCE AND CHARACTERISTIC OF ABR FOR LOW STRENGTH WASTEWATER

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Abstract. The performance and the characteristics of a laboratory-scale ABR (anaerobic baffled reactor) were investigated during different seasons (summer, spring, autumn and winter). ABR successfully achieved COD removal efficiencies 74% during summer, 68% during autumn/spring and 62% during winter. Compartment I, II and III showed high removal rate of COD during whole study period. At lower OLR (organic loading rate), COD removal rate was high. The analysis of biogas production during all seasons showed downward trend with increase of HRTs (hydraulic retention time). Compartment I showed high VFA (volatile fatty acid) synthesis compared to others compartments. The ABR has the potential to provide a greater efficiency and be applicable for all type of seasons and temperature conditions.
Keywords: *anaerobic baffled reactor (ABR); chemical oxygen demand; hydraulic retention time; volatile fatty acids; organic loading rate*

Introduction

Because of rapid urbanization and economic growth, world water resources are becoming constantly polluted and deficient in most of the region (Paraskevas et al., 2002). Worldwide, adequate sanitation and access to safe water is a big problem for billions of peoples (Moe and Rheingans, 2006). The demand is increasing for efficient, reliable and low cost wastewater treatment systems, particularly in scattered regions and where insufficient wastewater treatment systems were existing. Therefore, there is a need to implement sustainable and appropriate sanitation and wastewater management practices (Katukiza et al., 2012).

Conventional wastewater treatment systems are costly for small localities and housing societies (Nath and Sengupta, 2016). The wastewater treatment method is constrained by considerations of local regulation, population and topography, lead to challenging performance and design. Because of environmentally friendly and low energy requirement, ABR was found as an attractive method (Boonsawang et al., 2015), and suitable wastewater treatment solution for low income areas (Kamali et al., 2016). The biological advantages of the ABR are well documented, and from last decade anaerobic processes has proven to be a better alternative of wastewater treatment (Zhu et al., 2016). Over the last few decades, several papers have been published on ABR performance. Grobicki and Stuckey (1991) studied the hydraulic loading rates on mass transfer and reaction rate limitations. Nachaiyasit and Stuckey (1997) investigated the effect of shock loads on the performance of an ABR. Liu et al. (2007) studied

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hydrodynamic characteristics of ABR. Design simplicity, high treatment efficiency, non-sophisticated equipment, low operational and capital costs are main advantages of ABR (Zwain et al., 2014).

The ABR is a powerful anaerobic digester which internally comprises by a series of hanging and standing baffles, wastewater flow from one chamber to next under and over the baffles as flow from inlet to outlet (Ayaz et al., 2012). Treatment is achieved naturally selected anaerobic biota in the form of anaerobic digestion without application of oxygen or mechanical mixing. In addition, anaerobic digestion could be achieved by separation between HRT (hydraulic retention time) and SRT (solid retention time), that allow anaerobic microbes to remain within the reactor independently from the wastewater flow (Plósz, 2007). Although organic material and suspended solids are efficiently removed by ABR, the process has no or very little effect on nutrients (nitrogen and phosphorus) and pathogens removal (Nasr et al., 2009). Therefore, post-treamtent is needed in removing, residual COD and total suspended solids as well as reducing concentration of nutrients and pathogens. The main purpose of this research was to investigate seasonal performance of ABR for domestic wastewater. The reactor performance was evaluated under different HRTs and seasonal condition. A five chamber PVC made reactor selected for this study to provide a simple and low-cost treatment system for seasonal wastewater treatment. HRT, OLR and seasonal effect on COD removal, gas production and VFAs synthesis were studied.

Material and methods

Reactor setup

A lab-scale anaerobic baffled reactor was constructed from PVC material with dimension 1m long, 0.2 m wide and 0.75 m high with 100 L effective volume (*Fig. 1*). The reactor contained five compartments and each compartment subdivided into down-flow and up-flow units by using high/low vertical baffles. These baffles regulated the flow of wastewater in ABR. Each chamber was filled with 5 cm wide and 35 m long non-woven cloth to prevent biomass washout. Outlet of each compartment had DN10 sampling port and bottom equipped with mud tubes and valves. A peristaltic pump was used to adjusted flow rate.

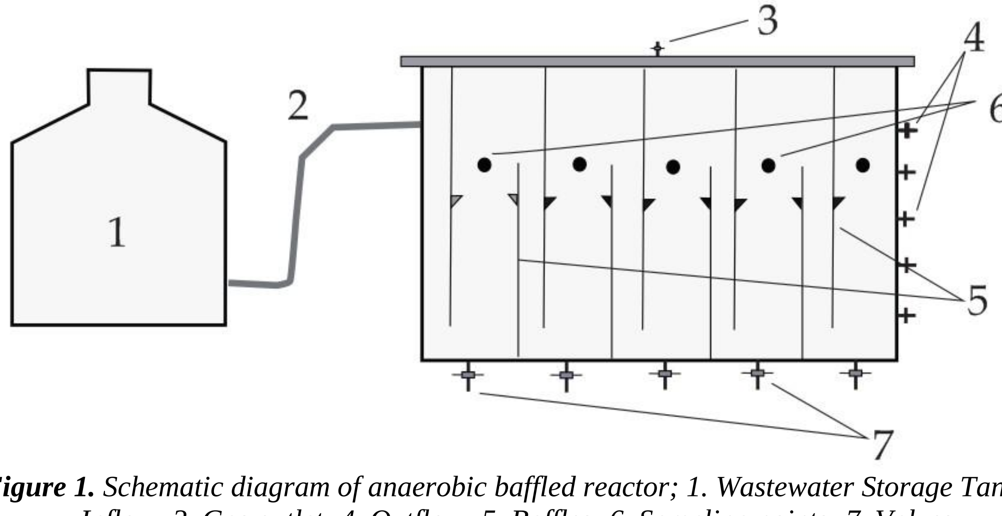

Figure 1. *Schematic diagram of anaerobic baffled reactor; 1. Wastewater Storage Tank; 2. Inflow; 3. Gas outlet; 4. Outflow; 5. Baffles; 6. Sampling points; 7. Valves.*

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Reactor setup

The raw wastewater was obtained from the campus of the Southeast University at Wuxi. The wastewater generated from dormitories, restaurants and laboratories of Universities campus. The quality of sewage fluctuated because of dilution by rainwater, and behaves similar as a decentralized wastewater. The sewage quality is presented in *Table 1*.

Table 1. *Main characteristics of the influent water*

Parameters	pH	COD[1]	TSS[1]	Temperature (˚C)		
		(mg l^{-1})		Summer	Autumn	Winter
Range	6.89 - 7.23	183.0 - 324.5	172 - 364	25 - 35	17 - 22	5 -15
Mean	7.06	258.4	276	30	20	9

[1]*In this table COD stand for chemical oxygen demand, whereas TSS is total suspended solids.*

Analytical methods

Standard methods (American Public Health Association, 2005) were used for analytical determination. Chemical oxygen demand (COD) was measured by closed reflux colorimetric method (Method 5220 D). DO and pH analyzed by DO200 and PH100 probes (YSI) respectively. VFA was measured by modified distillation method.

Experimental procedure

The experimental reactor had been running for all season from the system start-up. Air temperature during the summer, autumn and winter seasons was 25 – 35 ˚C, 15 – 20 ˚C and 3 – 12 ˚C respectively with ± 4 ˚C wastewater temperature. HRTs was adjusted 24 h, 48 h, 72 h and 96 h for summer, 48 h, 72 h, 96 h and 120 h for autumn/spring and 72 h, 96 h, 120 h and 144 h for winter season. During autumn and spring season temperature range was similar hence considered single season.

Data analysis

SPSS version-18.0 (SPSS incorporation Chicago, Illinois, USA) and MS-excel programs were used for data analysis and presentation.

System start-up

An ABR start-up is a complex process, slow growing anaerobic biomass first needs to be established in the reactor and reactor requires period of several months to reach full treatment capacity (Barber and Stuckey, 1999). Reactor was inoculated with anaerobic bacteria by activated sludge, which obtained from local wastewater treatment plant (WWTP), Wuxi, China. These added bacteria multiply and adapted to wastewater. Many factors can affect start-up of ABR such as concentration and composition of wastewater, pH, temperature, HRT, reactor size and structure etc. (Hassan et al., 2015). Potential problem can arise during start-up because of plug flow, low pH and accumulation of Volatile Fatty Acid (VFA) (Liu et al., 2010). Some approaches such as feed dilution, organic loading rate (OLR), periodic feeding and effluent recycling, can help to overcome these difficulties. Low loading start-up,

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reducing the concentration of organic matter promotes granular sludge growth, allowing the bacteria enough time to multiply before suspended solids are washed out (Sallis and Uyanik, 2003). For start-up, the reactor operated for 50 days with HRT 72 h and gradually reduced to 48 h and then 24 h until the COD removal efficiency stabilized at 60%, and PH stabilized between 7.03 - 7.23 (*Table 2*).

Table 2. *ABR start-up operational condition*

Phase	Time (days)	Temperature (˚C)	HRT[1] (Hours)	Volume Load (kg/m$_3$•d)	COD[2] Removal (%)
I	20	16 - 23	72	0.67 - 1.06	51
II	15	18 - 28	48	0.92 - 1.61	60
III	15	20 - 31	24	1.76 - 3.24	61

[1]*HRT = hydraulic retention time;* [2]*COD = chemical oxygen demand*

Results and discussion

COD removal

HRT is one of the most important factors affecting the COD removal in the anaerobic reactor (Ozgun et al., 2013). At higher HRT, contact time of sewage was increased in reactor which results in the improvement of COD removal rate (Chelliapan et al., 2014). But too long HRT decrease flow rate which unable to stirred anaerobic sludge. *Fig. 2* shows HRT relation with the COD removal rate during different seasons. HRTs were “24 h, 48 h, 72 h, 96 h”; “48 h, 72 h, 96 h, 120 h” and “72 h, 96 h, 120 h, 144 h” during summer, autumn and winter respectively. In general the trend is increase COD removal efficiency with the increase of HRT. The average COD removal efficiencies were 60%, 65%, 72%, and 74% during summer, 59%, 64%, 67% and 68% during autumn and 51%, 55% , 61% and 62% during winter. The increase of the HRT from 24 h to 72 h during summer, 48 h to 96 h during autumn and 72 h to 120 h during winter rises in the COD removal efficiency significantly but when HRTs increased from stated HRTs no significant changes in COD removal efficiency occurred. As compared to summer, during autumn and winter temperature was low. In those seasons microbial activities and metabolic rate was lower. Seasonal prolonging of HRTs helps to increase the contact time of microorganisms and the substrate to improve the microbial activity and thus COD removal rate. While too long increase in HRT effect reactor feeding and reduces the mass transfer between the sludge and the substrate (Bayo et al., 2016). Therefore no significant changes occurred in COD removal rate.

Fig. 3 demonstrate COD removal rate at different compartment of ABR at different HRTs during summer, autumn and winter seasons. First compartment showing higher removal efficiency compared to all other compartments and this followed by second, third, fourth and fifth compartment. As HRT increases the removal rate also increase. This was possibly the result of elevated substrate concentration which also increased substrate flux into the bioaggregates resulting increased of microbial growth (Pirsaheb et al., 2015). Removal rate in compartment I, II and III show high removal rate of COD in all seasons while compartment IV and V showing low removal rate probably because most of the COD has been removed in first three compartments and anaerobic microbes have low nutrients (Zhu et al., 2008).

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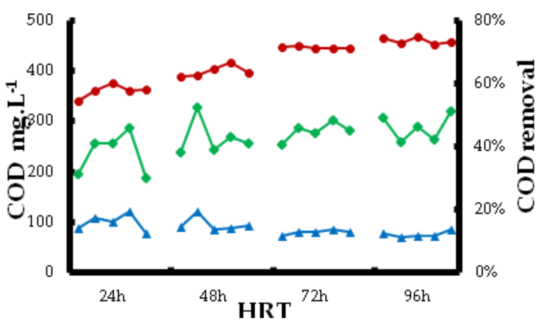
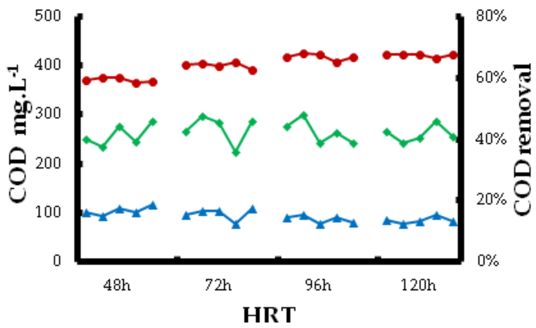
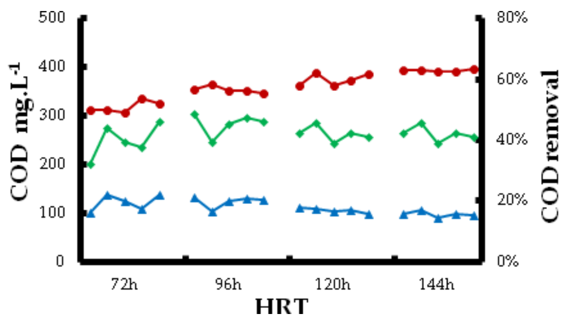


a. Summer



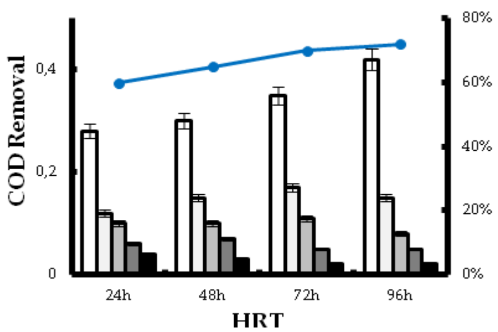
b. Autumn



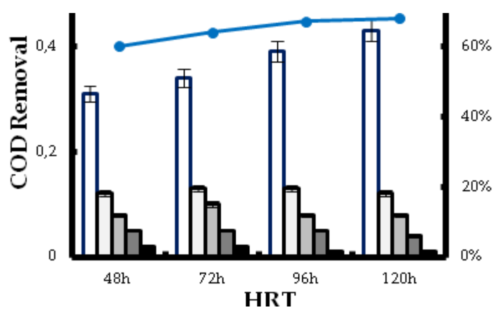
c. Winter

Figure 2. *COD removal efficiency of ABR under different HRTs*

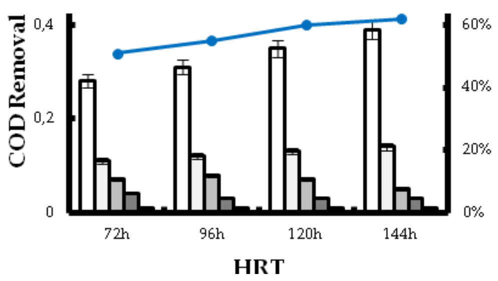
Influent water *Effluent water* *COD removal efficiency*



a. Summer



b. Autumn



c. Winter

Figure 3. *COD removal efficiency of ABR under different HRTs*

Compartment I *Compartment II* *Compartment III*
Compartment IV *Compartment V*

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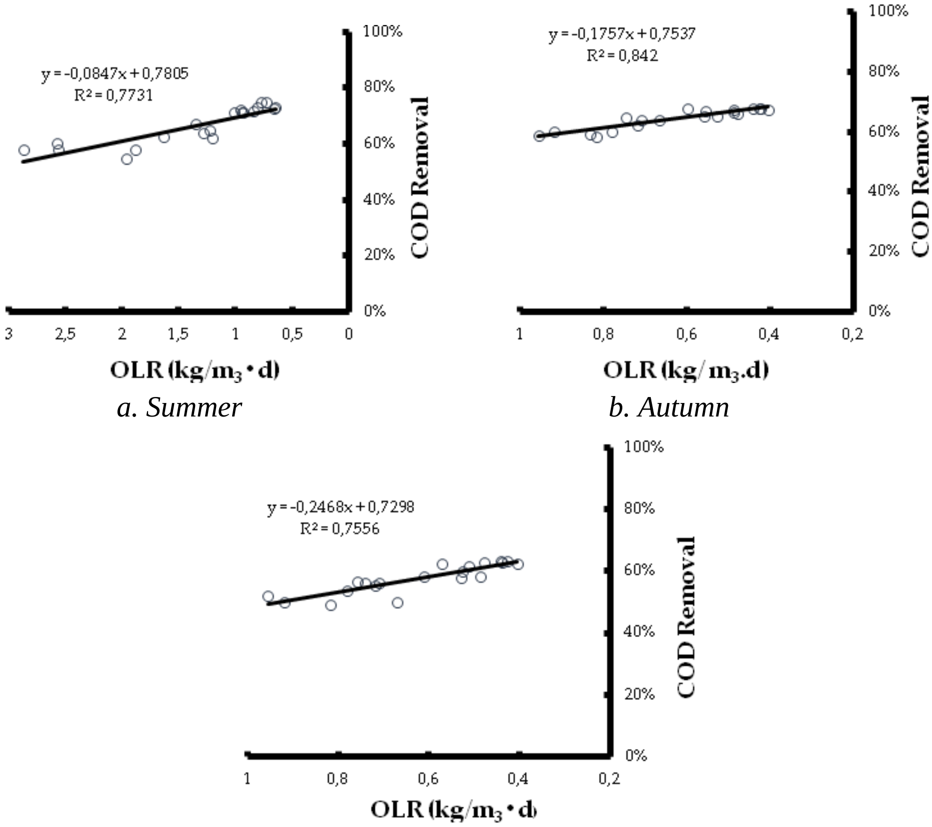
OLR is chief factor which indicates the amount of volatile solids to be fed into the reactor every day (Dhar et al., 2015). OLR control the growth of sludge, microbial activity and degradation efficiency. It’s directly linked to supply and demand relationship between substrate and microbes in the reactor (Boonsawang et al., 2015). *Fig. 4* shows the relationship of organic loading rate (OLR) with COD removal efficiency. With the change of OLR removal efficiency also affected, at the lower OLR removal efficiency was high. Increasing OLR gave an increased substrate concentration and elevated microbial growth resulting high COD removal rate (Kanimozhi and Vasudevan, 2014). However, further increased in the OLR dropped the removal efficiency. This might be due to the fact that high organic loadings brought a decrease in volatile suspended solids (VSS) and accumulation of inorganics subsequent destabilization of the reactor and process, which affects the reactor performance (Demirer and Chen, 2005).



a. Summer *b. Autumn*

c. Winter

Figure 4. *Showing the correlation between OLR and COD removal*

Biogas production

Reduction of organic matter in the reactor is directly related to the gas production. The final product of anaerobic biological degradation is biogas. The main composition of biogas produced in ABR is methane and carbon dioxide (Pereira et al., 2013). Methane and carbon dioxide production decrease from compartment I to V during all seasons. *Figure 5* illustrating the gas production during different seasons at different HRTs. Biogas production showed a wide fluctuating during entire study period. During

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all seasons, biogas production showed downward trend with increase of HRTs. This maybe at low HRT up-flow velocity in each compartment was high, which produce uniform mixing in the reactor and make the nutrients available resulting promotion of biogas production. While at higher HRTs although wastewater and sludge contact time was sufficient but because of low flow rate of wastewater in the reactor no mixing was taken place. During summer at 24 h of HRT the maximum average gas production was 1.53 L/ d and when HRT was 96 h, the lowest gas production was 0.43 L/ d. During autumn and winter when HRT increases from 48 h to 120 h and 72 h to 144 h gas production was decreased significantly from 0.55 to 0.14 L/ d and from 0.23 to 0.02 L/ d respectively. As compared to summer and autumn, during winter season temperature was very low, the gas production dropped significantly. Due to the increased solubility of gases at low temperatures, a large amount of biogas dissolved in water (Cadena-Pereda et al., 2012). Meantime, low temperature also impact on methanogen bacterial activities and suppressed biomethanation processes.

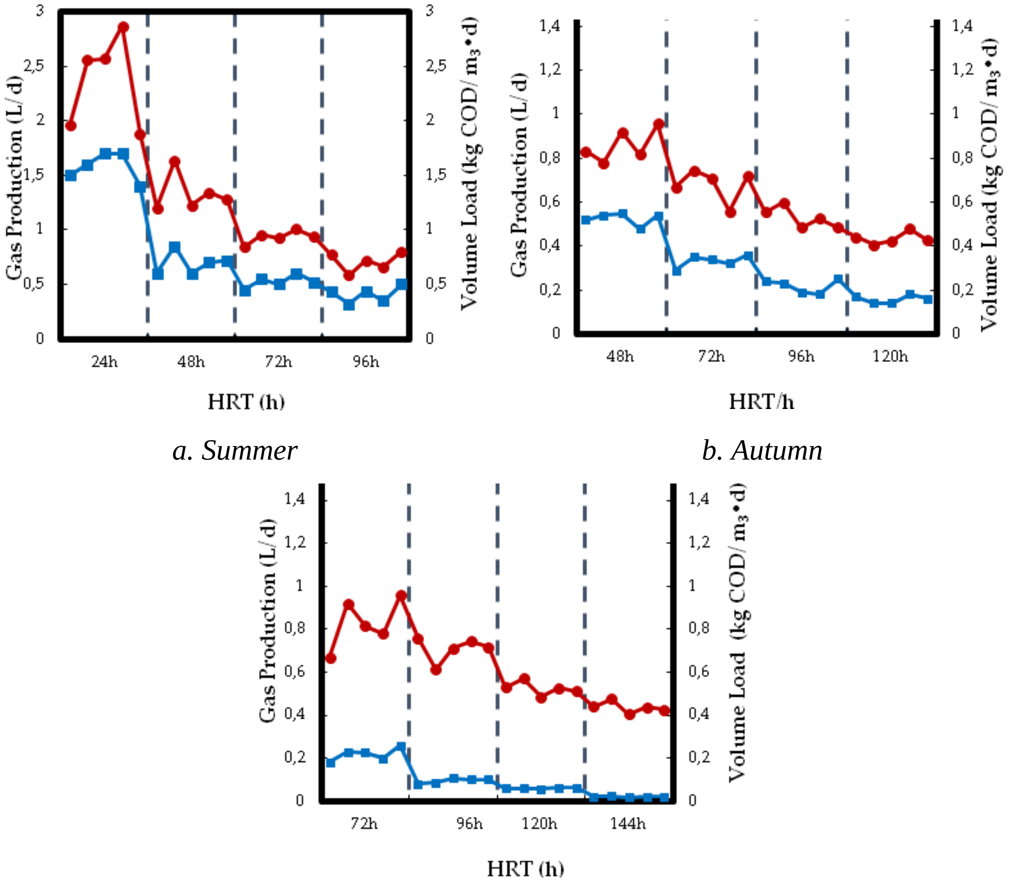

Figure 5. *Biogas production in ABR under different HRTs during different seasons*
Gas production ■ *Volume load* ●

Volatile fatty acids (VFA)

High concentration of VFA during anaerobic process can inhibit methanogenesis process. Under overloading conditions, methanogenic activity cannot remove volatile

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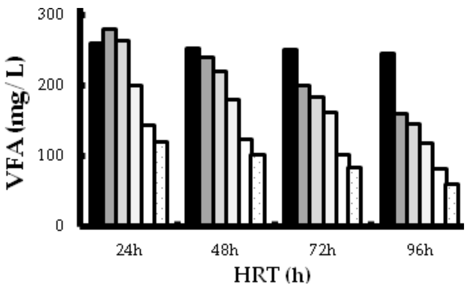
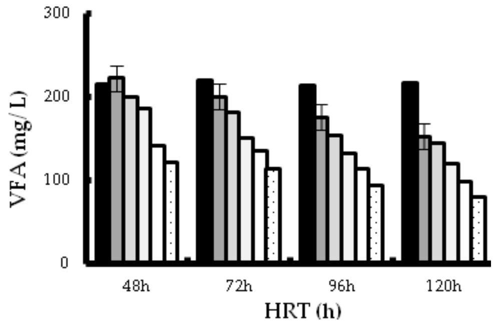
organic solids as result acids accumulate in the reactor and depress the pH at levels that inhibit acidogenisis or hydrolysis phase. It also shown even at optimum pH volatile fatty acids may contribute to reduced rate of hydrolysis. The pH is chief element to control anaerobic process. The optimum pH for methanogen organism is 6.6 - 7.6. At higher pH free ammonia can inhibit anaerobic metabolism, in addition, if pH not held fairly constant accumulation of excess volatile acids occur (Yirong, 2014).

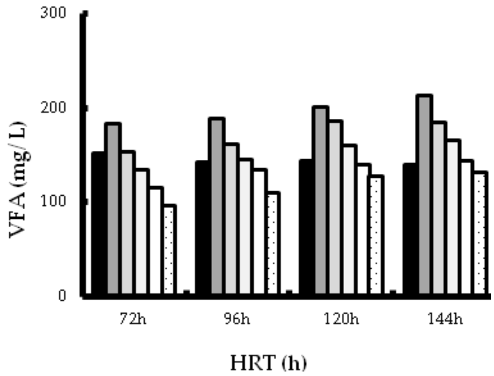
Figure 6 shows the VFA concentration during summer, autumn and winter seasons at different HRTs. When HRT prolonged, VFA concentration in reactor decreased. At all phases of HRTs, the first compartment had higher VFA concentration and this followed by II, III, IV and V compartment. This is mainly because the compartment I received the maximum organic load, thus anaerobic microbes produced higher concentration of VFA and descending order in other compartments. During summer and autumn seasons, compartment I had higher concentration of VFA than influent concentration at lower HRTs, but as HRTs increase compartment I shows decrease concentration compare to influent VFA. At lower HRT high flow rate cause acidification and supress the methanogen degradation of VFA (Chelliapan et al., 2011), however at higher HRTs when organic flow rate was low, most of the VFA was consumed. Throughout winter seasons mostly compartments showing higher VFA values than influent VFA. During winter seasons, low temperature limited the activities of methanogen bacteria, resulting accumulation of VFA.



a. Summer



b. Autumn



c. Winter

Figure 6. *VFA removal efficiency of ABR under different HRTs*

Inflow *Compartment I* *Compartment II*
Compartment III *Compartment IV* *Compartment V*

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Conclusions

Following are the main conclusion of the study:

- COD removal efficiency enhanced with increasing HRTs. During summer, autumn and winter season when HRTs were 72 h, 96 h and 120 h COD removal efficiency were 72%, 67% and 60% respectively.
- Most of the organic matters were degraded in first four compartments.
- The change of OLR would affect the organic matter removal efficiency and it is found that at low OLR removal efficiency was high.
- Biogas production decrease at low temperature, average gas production during summer, autumn and winter was 1.53, 0.58 and 0.23 L / d respectively.
- VFA concentration decrease with increase of higher HRT, and compartment I had higher production of VFA.
- The ABR has the potential to provide a greater efficiency and be applicable for all type of seasons and temperature conditions for organic loading, however post treatment is required for nutrients and pathogens removal.

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