HYDROGEN AND METHANE PRODUCTION FROM STARCH WASTEWATER IN A MESOPHILLIC ANAEROBIC BAFFLED REACTOR

***Ahmed Tawfik*[1], *Hosam Elsayed*[2], *and Hassan Dessouki*[2]

[1]*Egypt-Japan University of Science and Technology (E-Just), Alexandria, Egypt*
[2]*Banha University, Faculty of Science, Department of Chemistry, Cairo, Egypt*

ABSTRACT

Treatment of starch wastewater was investigated in a 30 l capacity pilot scale anaerobic baffled reactor (ABR) under mesophillic conditions. The reactor was operated at different hydraulic retention times (HRTs) of 72; 48 and 24 h. Corresponding organic loading rates (OLRs) were 8.7; 7.6 and 22 kg COD/m^3. d. The results showed that COD and BOD_5 removals exceeded 40 and 50% respectively at OLR of 22 kgCOD/m^3.d. The percentage COD recovered as methane in the gas phase was 56.7 and 43% at HRTs of 24 and 72 h, respectively. Methane yield averaged at 0.29 and 0.30 lCH_4 /g COD removed of ABR, at HRTs of 24 and 72 h., respectively, Increasing the BOD_5/COD ratio from 0.59 to 0.66 improved the removal efficiency of BOD_5 from 40 to 54% respectively. Methane yield averaged at 0.29 and 0.30 lCH_4 /g COD removed of ABR, respectively. Removal of COD $_{particulate}$ fraction of organics was found to be greater than COD $_{soluble}$ fraction. Sudden drop in pH from 7.8 to 6.7 and generation of volatile fatty acids (VFA) were observed in the first compartment due to acidogenesis and acetogenesis. The pH increased and VFA concentration decreased longitudinally down the reactor.

Key words: starch wastewater; anaerobic baffled reactor; HRT; SRT; Profile

1. INTRODUCTION

The manufacture of starch products involves significant usage of water; consequently resulting in large quantities of wastewater—starch processing wastewater (SPW). Generally, the chemical oxygen demand (COD) levels of SPW range from 6 to 19 g/l and it can impose heavy loads on the environment or be expensive in terms of sewer disposal (Jin et al., 2002). SPW contains a relatively high content of carbohydrates, cellulose, protein and nutrients, representing an important energy-rich resource, which can be potentially converted to a wide variety of useful products. Bioconversion is an advantaged way to recover useful resources from SPW, especially producing more valuable products, such as microbial biomass protein (Jamuna, et al., 1989; Jin et al., 1999) and biopesticide (Lu et al., 2007). However, people hesitate to use the microbial biomass protein because of its uncomfortable taste, high nucleic acid content and slow digestion. The high production cost and technical barriers to large-scale implementation also limit the application of biopesticide. Therefore, it is worthwhile to find a promising sustainable approach not only to safe disposal of SPW into water streams but also for useful energy production. In recent years considerable effort has been made in Egypt toward the development of more sophisticated anaerobic treatment processes, suitable for treating high strength wastes. In recent times, several reactor systems/configurations treating a wide variety of wastewaters have been conceived. Among them the anaerobic baffled reactor (ABR) has also been developed for the treatment of wastewaters by McCarty and coworkers (McCarty, 1981). It can be described as a series of UASB reactors (Barber and Stuckey, 1999). It uses a series of vertical baffles to force the wastewater to flow under and over them as it travels from inlet to outlet. Anaerobic bacteria within the reactor gently rise due to flow characteristics and gas production in each compartment, and settle. Probably, the most significant advantage is its ability to separate acidogenesis and methanogenesis longitudinally, allowing the reactor to behave as a two-phase system without the associated control problems and high costs. The reactor design is simple with no moving parts or mechanical mixing, making it relatively inexpensive to construct. Sludge generation is low and the sludge residence time (SRT) is high. Intermittent operation is also possible which facilitates treatment of seasonal wastewaters. An analysis presented by Orozco (1988) showed that for the same COD removal efficiency, the ABR required 39% less HRT than the up-flow anaerobic sludge blanket (UASB) reactor. The COD removal efficiencies of UASB reactor and ABR were compared by Bae et al. (1997) at increasing OLR. They found that, the COD removal efficiency of UASB reactor decreased slowly to 76% as OLR increased up to 10 kg COD/m^3.d, and abruptly deteriorated to below 50% at 15 kg COD/m^3.d. On the other hand, COD removal efficiency of ABR was generally higher than that of UASB reactor, and was found to be 72% even at an OLR of 20 kg COD/m^3.d. The authors concluded that the difference might have resulted due to the fact that the configuration of ABR provided more distinct phase separation than that of UASB reactor. An experimental study of Hutnˇan et al., (1999) was carried out to compare the performance of UASB reactor and ABR simultaneously at 37 °C using synthetic wastewater of COD of 6 g/l. Organic loading rate (OLR) was increased gradually from 0.5 to 15 kg/m^3.d. The dispersion number obtained for the ABR was two times lower than that obtained for the UASB reactor. From the comparison of the performance of reactors, the lowest biomass wash-out resulted from ABR. In the UASB reactor, significant biomass wash-out was observed at 6 kg/m^3.d while in the ABR no significant wash-out occurred even at 15 kg/m^3.d. Negligible gradients of pH and VFA concentration were observed along the UASB reactor. In case of ABR, differences observed along the reactor were noticeable. All four phases of the anaerobic process proceeded simultaneously in the UASB reactor. On the contrary, the compartmentalized design of the ABR was judged to be ideal to separate the phases of the anaerobic process. A faster biomass granulation was also observed in the ABR. Keeping these in view, investigations have been carried out to study the performance of an ABR at different OLRs (or HRTs) towards the treatment of high -strength starch wastewater. The present study was also aimed to integrate various aspects like (a) stable operation for a quite extended long period and (b) compartment-wise variation of various parameters

2. MATERIAL AND METHODS

2.1. Starch Wastewater

Starch processing wastewater (SPW) was collected from a starch manufacture plant located at 10^{th} of Ramadan, in which corn was used as raw materials. The treatment system was installed and operated at the main starch wastewater source of National Company for Maize Products (N.C.M.P). The starch wastewater was collected and continuously pumped to the treatment system. The average composition of starch wastewater is given in Table 1.

The results indicate that the starch wastewater has high organic content and suspended solids and nutrients. Anaerobic digestion would be an acceptable treatment method. The fluctuations in the wastewater characteristics are due to changes in what is happening in the plant during each period and discontinuous discharges of the starch's departments. Owing to the large fluctuations in the strength of the starch wastewater, the influent COD concentration showed large variations, making it difficult to use a constant organic loading rate. There is need for on-site treatment of the wastewater to protect the environment and reduce costs as heavy penalties are imposed for discharging substandard effluent into the urban treatment works. The big portion of organic content of the wastewater was in a soluble form (75%) and only 25 % was in particulate fraction as shown in Table 1. The high COD and BOD_5 value shows that the wastewater has high organic content and pH value of 7.2 indicates neutral of the wastewater. The ratio of BOD to COD was 0.64, which indicates that starch wastewater is biologically degradable. From Table 1 it was also observed that the wastewater has higher solid content.

Table 1. Mean characteristics of starch wastewater

Parameters	Unit	Min.	Max.	Average
pH		6.87	7.89	7.2±0.2
COD_{total}	mg/l	6270	38835	20483.6±6895
$COD_{soluble}$	mg/l	5808	24532	14619±3890
$COD_{particulate}$	mg/l	398	20241	5865±4500
$COD_{sol}/COD_{tot.}$		46	96.5	0.75±14
$COD_{part}/COD_{tot.}$		3.5	54	0.25±14
BOD_5	mg/l	3825	21748	12529±4323
BOD_5/COD		0.2	1.8	0.64±0.2
TSS	mg/l	230	8648	2112±1442
VSS	mg/l	207	8105	2021±1290
VSS/TSS		0.088	19.4	1.94±3.2
TKj-N	mg/l	867	2841	1821±329
NH_4-N	mg/l	446	1801	1156±285
Alkalinity	mg/l	2150	12150	7050±1757
VFA	mg/l	2731	14877	9639±2665
VFA/Alk.		0.66	1.95	1.4±0.2

2.2. Anaerobic Baffled Reactor (Abr) Pilot Scale

A pilot-scale ABR (Fig. 1) was fabricated using stainless steel sheets. The lower portion of the hanging baffles was bent at 45 °C to route the flow to the center of the up-flow chamber, thus achieving better contact and greater mixing of feed and biosolids (Bachmann et al., 1985). The total liquid volume of the ABR was 30l. The liquid volumes of each down-flow and up-flow chambers were 2.0 and 4.0 l, respectively. The reactor was housed in a temperature controlled chamber maintained at 35 °C. A peristaltic pump was used to feed the ABR with starch wastewater without additions of any other nutrient or trace elements.

2.3. Seed Sludge

The reactor was initially seeded with anaerobic sludge collected from anaerobic digester fed with municipal food waste. The harvested sludge with value of 40 gVSS/l was introduced uniformly into all six compartments of the ABR. Each compartment contained 3 l sludge with a total inoculated volume of 15 l. After seeding, the reactor was sealed and the head space above each compartment was flushed with oxygen-free nitrogen gas in order to displace residual air from the system.

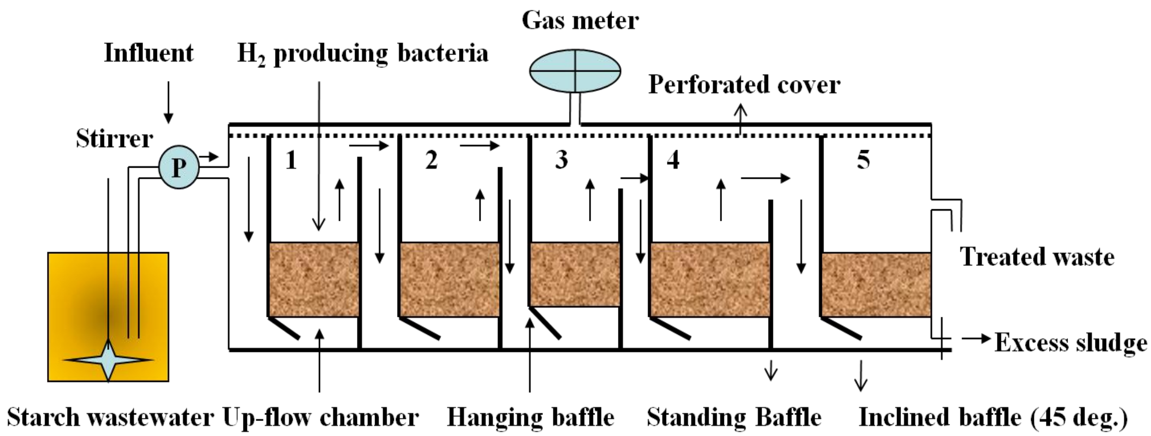

Fig. 1 schematic diagram of ABR fed with starch wastewater

2.4. Operational Conditions

Anaerobic baffled reactor (ABR) was operated at different hydraulic retention times (HRTs) and organic loading rates (OLRs) as shown in Table 2.

Table 2. operational conditions of ABR fed with starch wastewater

	Run 1	Run 2	Run 3
HRT (h)	72	48	24
OLR (kgCOD/m^3.d)	7.4	7.6	22
Flow rate (l/d)	10	15	30

2.5. Analytical Methods

The anaerobic reactor was daily monitored for pH, temperature, COD, and biogas. Volatile fatty acids (VFA), ammonical nitrogen, total phosphorus, BOD_5, TSS, alkalinity and VSS were measured twice/week. Samples were also collected for analysis from different compartments of ABR. All the parameters were analyzed according to APHA, (2005). Raw samples were used for COD_{total} and 0.45 µm membrane filtered samples for $COD_{soluble}$. The $COD_{particulate}$ was calculated by the difference between COD_{total}, and COD filtered respectively. The biogas constituents (H_2, CO_2 and CH_4) were analyzed by a gas chromatography (GC, Agilent 4890D) with a thermal conductivity detector (TCD) and a 2 m stainless column packed with Porapak TDS201 (60/80 mesh). Total volume of evolved gases was measured by acidified water displacement method.

3. RESULTS AND DISCUSSION

3.1.Performance Of The Abr System At Different Hrts

COD fractions removal and COD mass balance: the results presented in Fig. 2 shows the effect of HRT on the removal efficiency of COD via ABR treating starch wastewater. The results showed that decreasing the HRT from 72 to 24 h and increasing the OLR from 7.3 to 22 kgCOD/m^3.d does not affect seriously on the COD $_{total}$ removal efficiency. The reactor achieved a removal efficiency of 50, 42 and 44% for COD $_{total}$ at an HRTs of 72,48 and 24 h and OLRs of 7.3; 7.6 and 22 kgCOD/m^3.d., respectively. There was no significant difference in the effluent COD $_{total}$ between HRT of 72 and 24 d, thus, the HRT 24 h., operation is preferable since the working volume of the reactor could be reduced three times. A higher removal efficiency of COD (92–97%) was achieved by Zhu et al., (2008) who investigated ABR for treatment of soybean protein processing, at lower OLR of 1.2–6.0 kgCOD/m^3. d and longer HRT of 39.5 h. At low OLR of 4 kgCOD/m^3.d and high HRT of 5.4 d, (Chaiprasert et al., 2003) achieved a removal efficiency of 90% for COD $_{total}$ in anaerobic hybrid (AH) reactor treating cassava starch wastewater. These results demonstrated that in this investigation, ABR came under stress and could not cope with the increasing strength of the wastewater.

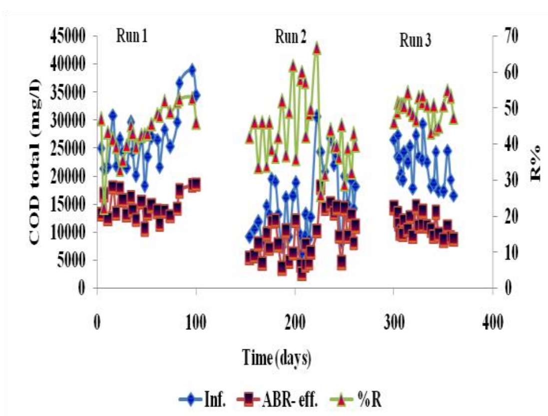

Fig. 2 variation of COD $_{total}$ at different HRTs

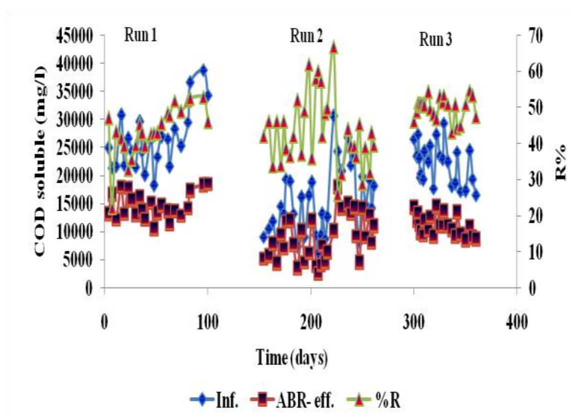

Fig. 3 variation of COD $_{soluble}$ at different HRTs

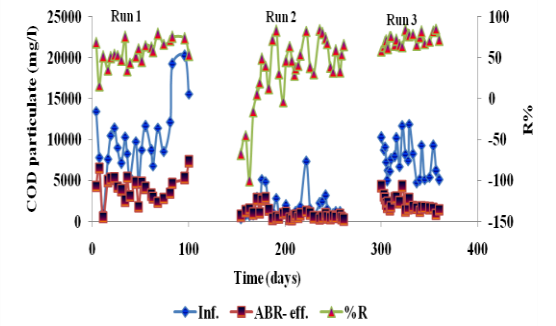

Fig. 4 variation of COD $_{\text{particulate}}$ at different HRTs

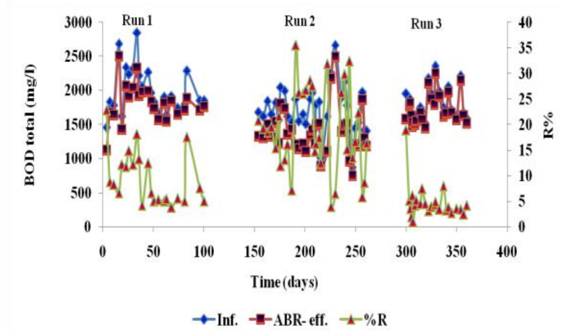

Fig. 5 variation of BOD$_5$ at different HRTs

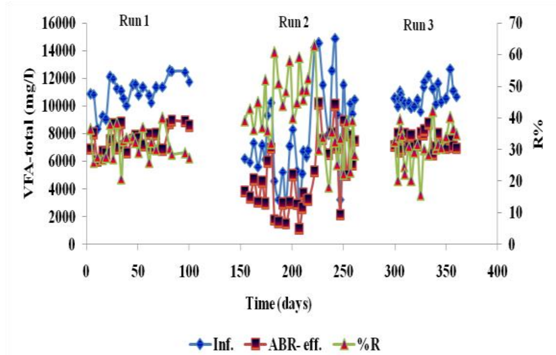

Fig. 6 variation of VFA at different HRTs

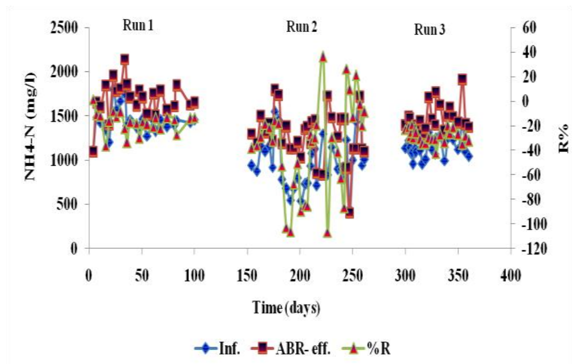

Fig. 7 variation of ammonia at different HRTs

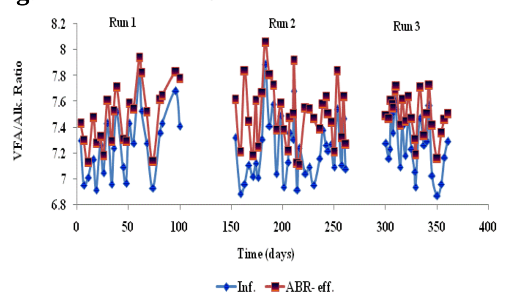

Fig. 8 variation of VFA/Alkalinity ratio at different HRTs

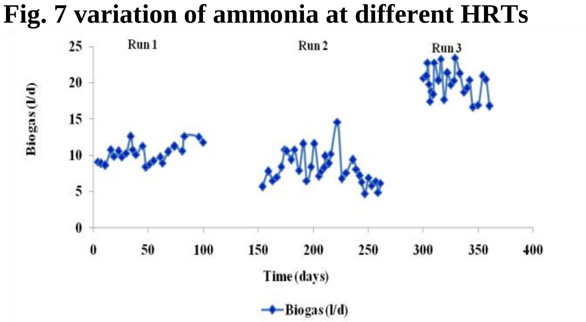

Fig. 9 biogas production at different HRTs

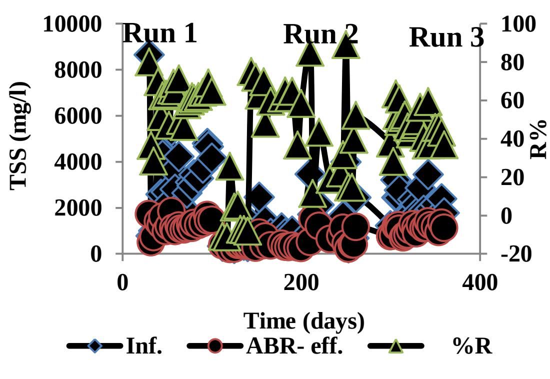

Fig. 10 TSS removal at different HRTs

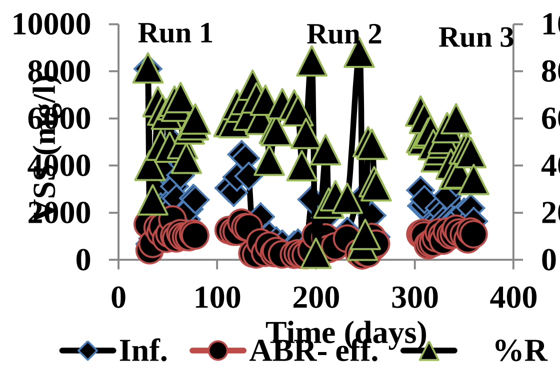

Fig. 11. VSS removal at different HRTs

For improving the efficiency of ABR treating starch wastewater, recycled of the effluent is a good option. However, Saritpongteeraka and Chaiprapat; (2008) found that increasing recirculation effluent from 0 to 0.5 raised the hydraulic loading on the ABR system treating high sulfate waste water and resulted in a drop of COD removal efficiency and methane yield.

Similarly, the removal efficiency of $COD_{soluble}$ was not seriously affected by decreasing the HRT as shown in Fig. 3. This was not the case for COD particulate, where increasing the OLR and decreasing the HRT improved the removal efficiency from 59 to 72% as shown in Fig. 4. However; the reactor achieved a low removal efficiency of 48% for $COD_{particulate}$ at OLR of 7.6 kgCOD/m^3.d and HRT of 48 h. This was mainly due to washout of the biomass which deteriorates the effluent quality for $COD_{particulate}$ (Fig. 3). Likely, Krishna et al., (2009), found that reducing the HRT from 20 to 6 h in ABR treating low-strength soluble wastewater resulted in escape of solids and decrease in COD removal efficiency. Therefore, in this investigation, sludge was intentionally discharged from the reactor which improved the removal efficiency of $COD_{particulate}$ at higher OLR of 22 kgCOD/m^3.d and short HRT of 24 h as shown in Fig. 4. Chaiprasert et al., (2003) found that Nylon fibers as supporting media in the anaerobic reactors treating cassava starch wastewater not only retained an essential biomass inside the system but also prevented the biomass loss from washout. The percentage COD recovered as methane in the gas phase was 56.7 and 43% at HRTs of 24 and 72 h, respectively. While treating low-strength synthetic wastewater using UASB reactor, Harada et al. (1994) reported that 63% of the incoming COD is converted into CH_4 gas. On the contrary Singh and Viraraghavan (1998) reported that only 35-45% of COD is converted by methanogens (for municipal wastewater). Polprasert et al. (1992) observed that while treating slaughterhouse wastewater using an ABR, around 31-55% of total COD entering into the reactor got converted to methane. 85% of the COD consumed was converted into CH_4 -COD in ABR treating low-strength soluble wastewater and (Krishna et al., 2009).

BOD removal efficiency: Fig. 5 shows the BOD_5 removal efficiency at different HRTs and OLRs. The results revealed that decreasing the OLR and increasing the HRT improved slightly the BOD_5 removal efficiency. The reactor achieved a removal efficiency of 54% at HRT of 72 h; 43% at HRT of 48h and 40% at HRT of 24 h. The biomass had a better chance of interaction with the substrate at an HRT of 72 h, which resulted in a higher specific BOD_5 removal rate. With the HRT shortened to 24 h, the ability of ABR to remove BOD_5 decreased substantially since the contact time between biomass and substrate declined. The outcome demonstrated that it was not exclusively a high amount of biomass (43 gVS/l) that was of great significance to the system's performance but also the mass distribution or diffusion, and the substrate contact time of the involved microorganism. Moreover; increasing the BOD_5/COD ratio from 0.59 to 0.66 improved the removal efficiency of BOD_5 from 40 to 54% respectively.

VFA, ammonia; TKj-N and biogas production*:* the results presented in Fig. 6 show that the removal efficiency of VFA was increased from 31 to 39 % when the HRT increased from 24 to 48 h. However; at an HRT of 72 h, the VFA removal efficiency was dropped to 31%. This mainly can be due to a higher influent concentration of ammonia of 1.14 g/l at an HRT of 72 h. The influent of ammonia was 0.97 g/l at an HRT of 48 h., as shown in Fig. 7. Moreover, the results showed that the ABR is very effective for ammonification process.

The ammonia concentration was significantly increased in the final effluent as shown in Fig. 7. The levels of ammonia were increased by values of 17-37%. Similar observations have been reported by Foxon et al. (2005). This was mainly due to the conversion of organic nitrogen in the influent under anaerobic conditions. Wiegant and Zeeman, (1986) reported that several inhibitory processes might play a significant role in the methane digestion of wastes. On the level of methanogenesis, inhibition by the total ammonia concentration may be associated with pH inhibition, substrate and end-product inhibition and other inhibition processes. Koster and Lettinga (1984) showed that methanogens were acclimated to an ammonia-nitrogen concentration of 2420 mg/l, methane production started immediately after incubation at ammonia- nitrogen concentrations in range of 605–3075 mg/l.

The results presented in Fig. 8 revealed that at low VFA/alkalinity ratio of 0.65, the VFA removal efficiency was higher (38%) as compared to VFA/alkalinity ratio of 0.78 and 0.73. Biogas production was significantly increased with increasing the OLR from 7.3 to 22 kgCOD/m^3.d as shown in Fig. 8. The reactor provided a CH_4 yield of 20 l/d at OLR of 22 kgCOD/m^3.d. This was probably the net result of increased substrate concentrations which increased the substrate flux into the bioaggregates thereby increased the growth rate of internal microbe. This led to an enhanced removal rate of intermediates to methane, the production of more gas, enhanced mixing. Furthermore, the organic removal rate was increased from 3.7 to 11.6 kgCOD/m^3.d when increasing the OLR from 7.3 to 22 kgCOD/m^3.d. Increasing loading by lowering HRTs generally increases biogas production (Saritpongteeraka and Chaiprapat 2008; Zhu et al., 2008). Although the setup of this experiment was not designed to measure gas composition of each compartment, the highest proportion of hydrogen producing bacteria would be expected from the first compartment, while the higher methane percentage gas would be from the subsequent compartments. Activity partitioning between hydrogen producing bacteria and methanogenesis would occur in ABR; hence, the first compartment could be used as a hydrogen producing reactor, which will provide a more suitable environment for methane producing in the later compartments. It is important to note that seed of the ABR was harvested from a reactor for hydrogen production from municipal food waste. With this ABR operation, selection pressure took place and would result in the dominance of hydrogen producing bacteria in the front compartments. This assumption is confirmed by the results for biogas composition. The methane content was only 34%. Methane yield averaged at 0.29 and 0.30 lCH_4 /g COD removed of ABR, respectively, but approximately 14% less than theoretical value of 0.35 lCH_4 /g COD removed. This could be due to the biomass needs more energy to develop and adjust itself to adequately sustain its working performance toward the increasing wastewater strength. Observed methane yield refers only to the fraction of COD removed that is effectively converted to methane. However, other parts of COD may have been removed through other means such as solid accumulated in the reactor, part of the VFA adsorbed on to the sludge, or precipitation of some compounds within the reactor (Pereira et al., 2002). In this investigation, a big part of influent SS was adsorbed into the sludge bed, hence, tends to accumulate inside the reactor and not converted to biogas for a long period of time. The CH_4 content amounted to only 33.6%, CO_2 (51.2%) and hexane (13.6%). The reason for low CH_4 content is not exactly known but it is speculated that at high OLR, the presence of carbon dioxide in biogas becomes more evident since the digestion may as well occur at the upper part of the reactor.

TSS, VSS and total-P removal efficiency: the results in Figs. 10 and 11 shows that the ABR is effective for removal of TSS (64%) and VSS (63%) at an HRT of 72 and OLR of 7.3 kgCOD/m^3.d. The removal efficiency was dropped at lower HRT and higher OLR as shown in Figs 10 and 11. Suspended solids in wastewater are known to affect anaerobic digestion adversely (Elmitwalli, 2000; Aiyuk et al., 2004). They decrease sludge activity due to adsorption and entrapment, limit substrate transfer, lead to the formation of scum layers, inhibit granulation, and enhance sludge production, causing frequent need to desludge reactors. Total phosphorous removal was kept constant at a level of 49% as shown in Fig. 12. The removal of phosphorous was mainly due to the precipitation of phosphorous in the suspended form.

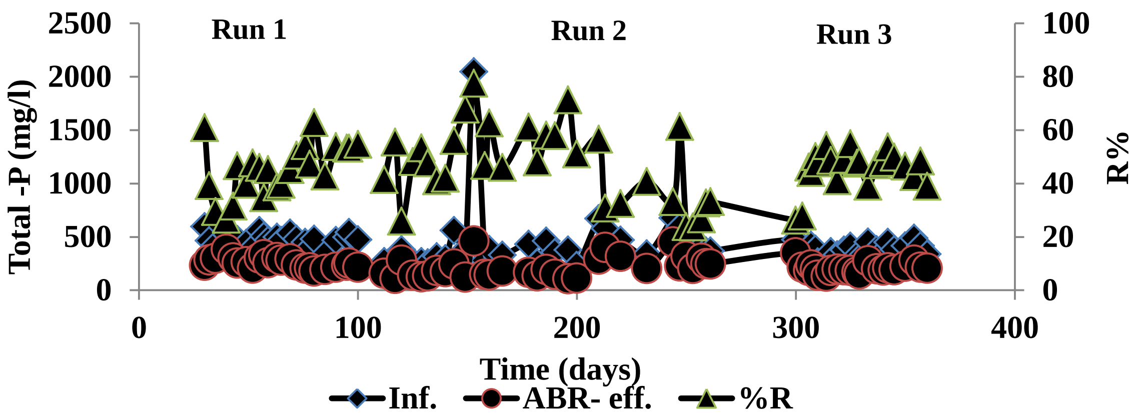

Fig. 12. Total phosphorous removal at different HRTs

3.2. ABR Profile

Average profiles of COD fractions (COD $_{total}$; COD $_{soluble}$ and COD $_{particulate}$), pH, and VFA are presented in Table 3 to follow the changes as wastewater passed through the ABR compartments. COD $_{total}$ decreased as the wastewater moved from compartment 1 to 5. It is important to note that as the HRT increased or OLR decreased, compartment-wise COD reductions increased. In compartment 1, COD reduction was 11.8, 13.7 and 21.3% at HRTs of 4.8, 9.6 and 14.4 h respectively. Unlikely, Polprasert et al., (1992) found that at OLR of 0.87 kg/m^3.d most of the COD removal efficiency occurred in the 1st compartment. Whereas, at OLR between 1.82 and 4.73 kg/m^3.d, the significant decrease of COD concentration within the first two compartments were observed. Manariotis and Grigoropoulos, (2002) reported that most of the organic matter was removed in the first two chambers as COD removals in the first three compartments were 56.1, 22.4 and 5.3%, respectively for ABR treating, low-strength wastewater at an HRT of 12 h.

COD $_{particulate}$ and COD $_{soluble}$ profiles for ABR showed similar trend as shown in Table 3. From the results it is quite clear that the COD $_{particulate}$ and COD $_{soluble}$ removal was gradually increased from compartment 1 to compartment 5. When the HRT was increased to higher value (24, 48 and 72 h) it shifted to the next few compartments like COD $_{total}$. The pH profiles for the ABR at 24 and 72 h HRTs are shown in Table 3. Sudden drop in the pH in the first compartment is quite noticeable. It gradually increases as wastewater moves towards the later compartments. The pH in the effluent of ABR was always found close to 7. The pH in compartment 1 was lowest. Dama et al. (2002) have found that the earlier compartments had a lower pH as the acidogenesis and acetogenesis take place in these compartments. The pH values increased down the reactor (near effluent point) due to the degradation of VFA in the later compartments (Baloch and Akunna, 2003). The distinct pH profile is a further indication of the degree of different phases created within the system.

The VFA concentration increased in the 1st compartment and afterwards decreased longitudinally down the reactor (Table 3). The highest VFA concentration was found in the first compartment with average value of 13800 mg/ l at 4.8 h HRT. In a compartmental level, pH drop was observed in the first compartment and it steadily increased as the wastewater passed through the subsequent compartments (Table 3). It is interesting to note that VFA also increased the most at the first compartment. This indicated that, hydrogen was produced in the compartment 1. After the first compartment, VFA decreased slowly as the wastewater moved through the reactor. The VFA concentration in every compartment decreased with the increasing HRT from 4.8 to 24 h. VFA profile demonstrated that hydrolysis and acidogensis were the main biochemical activities occurring in the first few compartments (Akunna and Clark, 2000; Baloch and Akunna, 2003). The methanogenesis also appears to be dominant in the last few compartments. These observations suggest that the ABR system promoted a systematic selection in the different compartments in such a manner as to bring out phase separation. Wang et al. (2004) while treating high strength wastewater using ABR also reported that the total VFA concentration decreased longitudinally down the reactor from compartment 2.

Table 3. ABR profile results at different HRTs

		COD t	%R	COD s	%R	CODp	%R	TVFA	%R	pH
HRT (h)	SPW	36548		17342		19206		12511		7.2
4.8	C1	32200	11.8	15009	13.5	17191	10.5	13800	10.3	6.1
9.6	C2	30789	15.7	14300	17.5	16489	14.1	12511	0	6.2
14.4	C3	24800	32.1	13900	19.8	10900	43.2	10237	18.2	6.7
19.2	C4	18900	48.3	11200	35.4	7700	59.9	9789	21.8	6.9
24	C5	17332	52.6	10564	39.1	6768	64.7	8943	28.5	7.0
	SPW	19436		13200		6236		5270		7.4
9.6	C1	16800	13.7	11245	14.8	5555	10.9	6543	-24.2	6.3
14.4	C2	14300	26.4	9786	25.9	4514	27.6	4532	14.0	6.3
28.8	C3	10897	43.9	8765	33.6	3897	37.5	3209	39.1	6.5
38.4	C4	8976	53.8	7654	42.0	3000	51.9	3009	42.9	6.7
48	C5	8900	54.2	6754	48.8	2189	64.9	2910	44.8	6.9
	SPW	22478		14522		7956		10226		7.65
14.4	C1	17680	21.3	12390	14.7	5290	33.5	9786	4.3	6.6
28.8	C2	15432	31.3	11908	18.0	3524	55.7	8674	15.2	6.6
1.8	C3	13645	39.3	8765	39.6	4880	38.7	6000	41.3	7.0
43.2	C4	11400	49.3	8000	44.9	3426	56.9	5432	46.9	7.2
72	C5	10271	54.3	7489	48.4	2782	65.0	5321	47.9	7.3

4. CONCLUSIONS

- The results showed that COD and BOD_5 removals exceeded 40 and 50% respectively at OLR of 22 kgCOD/m^3.d. The percentage COD recovered as methane in the gas phase was 56.7 and 43% at HRTs of 24 and 72 h, respectively. Methane yield averaged at 0.29 and 0.30 lCH_4 /g COD removed of ABR, at HRTs of 24 and 72 h., respectively.
- Increasing the BOD_5/COD ratio from 0.59 to 0.66 improved the removal efficiency of BOD_5 from 40 to 54% respectively. Methane yield averaged at 0.29 and 0.30 lCH_4 /g COD removed of ABR, respectively.
- Removal of $COD_{particulate}$ fraction of organics was found to be greater than $COD_{soluble}$ fraction. Sudden drop in pH from 7.8 to 6.7 and generation of volatile fatty acids (VFA) were observed in the first compartment due to acidogenesis and acetogenesis. The pH increased and VFA concentration decreased longitudinally down the reactor.
- VFA profiles tend to indicate that compartmentalization in ABR serves to separate acidogenic and methanogenic activities longitudinally through the reactor, with the highest portion of acidogenic activity in the first compartment.

REFERENCES

[1]. Jin, B., Yan, X.Q., Yu, Q., Van-Leeuwen, H.J., 2002. A comprehensive pilot plant system for fungal biomass protein production and wastewater reclamation, Adv. Environ. Res. 6 179–189.

[2]. Jamuna, R., Ramakrishna, S.V., 1989. production and removal of organic load from cassava starch industry by yeasts, J. Ferment. Bioeng. 67, 126–131.
Jin, B., van-Leeuwen, H.J., Patel, B., Doelle, H.W., Yu, Q., 1999. Production of fungal protein and glucoamylase by *Rhizopus oligosporus* from starch processing wastewater, Process Biochem. 34, 59–65.

[3]. Lu, N., Zhou, S.G., Chang, M., Ni, J.R., 2007. Factors affecting the production of *Bacillus thuringiensis* biopesticide using corn steepwater as raw material, Chin. J. Environ. Eng. 1 (9), 126–130.

[4]. Zhu, G-F., Li, J-Z, Wu, P., Jin, H-Z, Wang, Z., 2008. The performance and phase separated characteristics of an anaerobic baffled reactor treating soybean protein processing wastewater Bioresource Technology 99, 8027–8033

[5].Aiyuk, S.E., Amoako, J., Raskin, L., Van Haandel, A., Verstraete, W., 2004a. Removal of carbon and nutrients from domestic sewage using a low-cost, integrated treatment concept. Water Res. 38, 3031–3042.

[6]. Elmitwalli, T.A., 2000. Anaerobic treatment of domestic sewage at low temperature. Ph.D. Thesis. Wageningen University, Wageningen, The Netherlands.

[7]. Chaiprasert, P., Suvajittanont, W., Suraraksa, B., Tanticharoen, M., Bhumiratan. S., 2003. Nylon fibers as supporting media in anaerobic hybrid reactors: it's effects on system's performance and microbial distribution. Water Research 37, 4605–4612.

[8]. Akunna, J.C., Clark, M., 2000. Performance of a granular-bed anaerobic baffled reactor (GRABBR) treating whisky distillery wastewater. Bioresour. Technol. 74, 257–261.

[9]. American Public Health Association (APHA), 2005. In: Standard Methods for the Examination of Water and Wastewater, 19th ed. Washington, DC, USA.
[10]. Barber, W.P., Stuckey, D.C., 1999. The use of the anaerobic baffled reactor (ABR) for wastewater treatment: a review. Water Res. 33 (7), 1559–1578.

[11]. Dama, P., Bell, J., Faxon, K.M., Brouckaert, C.J., Huany, T., Buckley, C.A., 2002. Pilotscale study of an anaerobic baffled reactor for the treatment of domestic wastewater. Water Sci. Technol. 26 (9), 263–270.

[12]. Koster, I.W., Lettinga, G., 1984. The influence of ammonium nitrogen on the specific activity of palletized methanogenic sludge. Agr. wastes 9, 205–216.

[13]. Lissens, G., Vandevivere, P., Baere, L.D., Biey, E.M., Verstraete, W., 2001. Solid waste digestors: process performance and practice for municipal solid waste digestion. Water Sci. Technol. 44 (8), 91–102.

[14]. Wiegant, W.M., Zeeman, G., 1986. The mechanism of ammonia inhibition in the thermophilic digestin of livestock wastes. Agr. Wastes 16, 243–253.

[15]. Polprasert, C., Kemmadamrong, P., Tran, F.T., 1992. Anaerobic baffled reactor process for treating a slaughterhouse wastewater. Environ. Technol. 13, 857–865.

[16]. Manariotis, I.D., Grigoropoulos, S.G., 2002. Low-strength wastewater treatment using an anaerobic baffled reactor. Water Environ. Res. 74, 170–176.

[17]. G.V.T. Gopala Krishna, Pramod Kumar, Pradeep Kumar. Treatment of low-strength soluble wastewater using an anaerobic baffled reactor (ABR). Journal of Environmental Management 90 (2009) 166-176

[18]. Kanyarat Saritpongteeraka, Sumate Chaiprapat. Effects of pH adjustment by parawood ash and effluent recycle ratio on the performance of anaerobic baffled reactors treating high sulfate wastewater Bioresource Technology 99 (2008) 8987–8994