Effect of Hydraulic Retention Times on the Performance of a Partially Packed Upflow Anaerobic Fixed Film System in the Treatment of Synthetic Rubber Processing Wastewater

Nor Faekah Ismai l, Fatihah Suja

Abstract: The aim of this study to investigate the performance of a partially packed up-flow anaerobic fixed film (UAFF) reactor at hydraulic retention times (HRT) of 17, 14, 10, 8 and 5 days. The reactor was fed with high strength synthetic wastewater that had a chemical oxygen demand (COD) concentration of 6550 ± 380 mg/L and organic loading rate (OLR) of 0.5, 0.6, 0.7, 0.8 and 1.3 g COD/l/day equivalent to HRT of 17, 14, 10, 8 and 5 days, respectively. The anaerobic degradation parameters such as the COD effluent concentration, COD removal percentage, volatile fatty acids (VFA), alkalinity, pH, biogas composition, biogas volume and ammonia effluent concentration were investigated. Results showed that the total COD removal efficiency of 97 ± 0.2, 96 ± 0.2, 92.5 ± 4.5, 91.5 ± 4.5 and 86 ± 6.5 % at HRT of 17, 14, 10, 8 and 5 days respectively. The UAFF showed stable operation with effluent volatile fatty acid (VFA) less than 400 mg/L and alkalinity within the optimum range of 1000 – 2000 mg/L. The buffering capacity for all HRTs were below the maximum allowable limit of 0.5 with pH variation around 6 – 8 throughout the experimental period. Moreover, the average methane percentage showed a moderately constant profile with the highest methane production obtained was 48.2% at HRT of 5 days and was unaffected by reduced HRT and high ammonia concentration of 208 mg/L. These results show that methane forming bacteria were adapted to its surrounding which was contained high COD at reduced HRTs and did not significantly affect the reactor performance.

***Index Terms*: Keywords: Anaerobic Digestion, Fixed Film, Hydraulic Retention Time, Packed Column, Methane Production.**

I. INTRODUCTION

Rubber latex is one of the most widely used groups of material in engineering products. The advantages of rubber such as elasticity and high chemical resistance make them dominant in various applications including tyres, gloves and other variety of products. Rubber latex production produce large amount of wastewater into the water bodies. These wastewater are highly polluted and mainly produce from several processing steps such as coagulation, centrifugation, lamination, washing, drying and etc [1].

Generally, wastewater discharged from natural rubber processing factories contained a high concentration of organic matter, ammonia and sulfate. Ammonia mainly used in preservation of rubber latex whereas sulfuric acid is used to recover rubber particles [2]. These chemicals affect quite harmful to the ecology and the health of people living in the surrounding environment due to discharging the effluent to the receiving waters. High level of ammonia is harmful to anaerobic process. More or less, ammonia from rubber processing wastewater have not been treated completely yet [1]. In addition, nitrogen could leads to undesirable eutrophication, economic loss, methemoglobinemia in infants, and deteriorates agriculture sector.

Various technologies applied in Malaysia, to treat waste water from natural rubber processing factories. These rubber industries have implemented treatment facilities that consistent with regulations. Technologies that have been implemented have their owned advantages and limitations such as simplicity of the treatment design, flexibility and effectiveness of the operation, easy to fix when there is technical problems and low costing in implementation and maintenance. Recent work has focused on treatment of rubber processing wastewater by effective microorganism using anaerobic sequencing batch reactor (ASBR) [3]. The ASBR can successfully retain and treat high solids content wastewater without any problem such as clogging of solids [4]. However, instability of effective microorganism occurred and cannot be survived due to short treatment period applied. [5], in his work used membrane bioreactor to treat natural rubber latex wastewater with influent COD 3500, 4500 and 5500 mg/L and removal efficiency of 96.99, 94.36 and 93.63% respectively .

According to our knowledge, treatment of rubber processing wastewater using anaerobic filter at short retention time and shock loading has been poorly studied with anaerobic fixed film digester. For instance, in the treatment of rubber thread wastewater was studied by [6] using anaerobic filter packed with aquarium media and operated at OLR 11.8 g COD/l/day and HRT of 10 days, and proved its removal COD efficiency up to 80% with influent COD concentration of 6100 mg/L.

Various studies have been

Revised Manuscript Received on 04 May 2019

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conducted in the literature on the effect of hydraulic retention time (HRT) on anaerobic digestion. In the treatment of palm oil mill using suspended growth anaerobic reactor, the performance of the reactor with respect to COD reduction was found to be affected by HRT [7]. [8], found that the soluble COD content in the effluent of soluble synthetic sugar waste increased with decreasing HRT during start-up of a hybrid anaerobic digester. Several treatment has been developed which can treat rubber processing wastewater in short retention period. With the use of a fixed film in the anaerobic reactor, it can reduce machine-driven mixing, more stable at higher loading rates, and high ability in handled toxic shock loads and organic shock loads, consequently simplifying the construction of the reactor [9]. This reactor also offers very quick recovery after a period of starvation [10]. However, the reactor can be clogged by an increase in biofilm thickness and/or a high suspended solids concentration in the waste water.

The objective of this study was to investigate the anaerobic digestion of synthetic rubber processing wastewater in a partially packed up-flow anaerobic fixed film digester. To be precise, the aim was to study the effect of HRT and COD/N ratio at different concentration on removal rate and methane productivity. It is desirable to control and monitor the parameters to prevent digester failure. Unstable reactor can be indicated by a drop in the methane production rate, a drop in the pH, or a rise in the volatile acid concentration (VFA).

II. METHODOLOGY/MATERIALS

A. Experimental Set-up

The anaerobic reactor has a total volume of 8.8 L, and the working volume is 7.0 L. It was made up of an acrylic column that has an internal diameter of 15 cm and an overall height of 50 cm. It consists of 5 main pipes: the feeding inlet pipe, effluent outlet pipe, recycle pipe, gas pipe and sludge outlet pipe. The reactor was operated at ambient temperature (28 – 32°C) and no temperature control was carried out. Wire coir was installed at the upper and lower parts of the reactor to support the biofilm structure. The UAFF reactor used in this study is shown in Fig. 1.

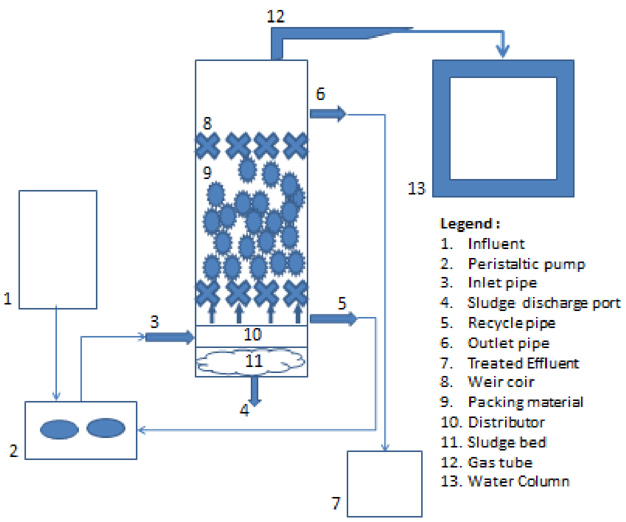

Fig. 1. The schematic of the partially packed up-flow anaerobic fixed film (UAFF) reactor.

To maintain the reactor in anaerobic condition, the reactor was installed with a plate at both ends to prevent the existence of the oxygen. A tubular PVC microbial filter 5 mm in height, with a 1.8 mm internal diameter and 2.0 mm external diameter, was loaded into approximately 2.9 L of liquid in the reactor. To distribute the feed uniformly, an influent liquid distributor was mounted at the base of the column. Substrate was semi-continuously fed to the reactor through the base using a peristaltic pump (Cole Parmer, Masterflex L/S).

A 3 L Tedlar Bag was used to collect the biogas generated during the degradation process and analyzed its composition. A sample of treated effluent was collected from the upper part of the reactor after the settling period (according to each HRT), and the remaining content was stirred for 5 min to collect a sample of the mixed effluent.

B. Feed Solution

Table I shows the characteristics of natural rubber processing wastewater obtained from Malaysian Rubber Development Corporation (MARDEC) Berhad, Mentakab, Pahang which was sampled directly from discharged point of rubber processing waste water. In order to gain wide range of COD concentration of natural rubber processing waste water, synthetic rubber wastewater shown in the Table I was prepared.

Table I: Characteristics of the feed solution (synthetic wastewater) and natural rubber processing wastewater.

Parameter	Natural Rubber Processing Wastewater	Synthetic wastewater
pH	6.32 – 6.82	7.12
$COD_{soluble}$	1360	5900 – 6500
NH_3-N	61 – 65	98 – 208
Total Nitrogen	95 – 220	250
Total Phosphorus	70 – 86	70
Suspended Solids	214 – 226	-
Volatile Suspended Solids	151 – 159.5	-

• all parameter units in mg/L except for pH

The prepared synthetic wastewater a few times higher in COD as compared to the real wastewater in order to imitate the average COD concentration of natural rubber processing waste water from different sources as based on previous studies (Table II). Waste water discharged from latex rubber processing usually contains high level of COD, BOD and SS. These characteristics vary from country to country due to

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difference in raw latex and applied technique in the process. The main source of the pollutants is the coagulation serum, field latex coagulation, and skim latex coagulation. These compounds are readily biodegradable and this will result in high oxygen consumption upon discharge of wastewater in receiving surface water.

Table II: Characteristic of natural rubber processing waste water from different sources based on previous research.

Parameter	[5]	[11]	[2]	[1]	[12]
pH	3.88	7.64 ± 2.1	5.54 ± 0.54	8.09	7.75 ± 1.1
Total Solid	258	1028.5 ± 119	1780 ± 1260	468	226 ± 13.9
Total Volatile Solid	-	-	1050 ± 760	-	159.5 ± 7.7
COD	3488	826 ± 1.7	9710 ± 2600	13981	1183.5 ± 150.5
Total Nitrogen	468	240 ± 2	1370 ± 480	972	227.5 ± 14.4
Total Phosphorus	-	80 ± 0.1	-	-	92.34 ± 13.9
Ammonia Nitrogen	326	296 ± 1.8		686	61.4 ± 6.4

The composition of the feed solution (synthetic wastewater) for 1 L is detailed in Table III.

Table III: Composition of the feed solution (synthetic wastewater) for 1 L.

Name of chemicals	Quantity (mg/L)
Glucose	5300
Meat extract	840
$CaCl_2$ 2H2O	61.2
MgSO4 7H2O	64.3
NH_4Cl	333.3

The feed rate was increased according to the tabulated values in Table IV.

C. Reactor Operation

The inoculum for seeding was a mixture of digested sludge taken from an anaerobic pond of the Malaysian Rubber Development Corporation (MARDEC) Berhad, Mentakab, Pahang. The digested sludge was tested for its chemical composition. The digested sludge, which contained 633,545 mg/L TS and 83,245 mg/L VS and a pH of 6.62-6.92, was passed through a screen to remove debris before 0.85 L was loaded into the reactor. The reactor was left for 1 week to allow time for the sludge to stabilize. The start-up of the reactor process took about 30 days to complete by monitoring the pH and biomass content of MLSS and MLVSS of sludge was 8020 and 2870 mg/L respectively.

The experimental operation period was then begun by pumping daily about 0.5 L corresponding to the initial organic loading rate (OLR) of 0.5 g COD/l/d. The COD concentration was kept constant at 6.1 ± 0.4 g/l. After the reactor reached stable COD removals at ±5% with more than 80% removal, the loading was gradually increase up to 1.3 g COD/l/d by increasing the incoming volume. Simultaneously, the HRT was kept reduced. The feed rate was increased according to the tabulated values in Table III.

Table IV: Operational characteristics of the UAFF during the study of the reactor performance at reduced HRT.

HRT (days)	Feed flow rate, Qin (L/d)	Corresponding OLR (kg COD/m^3.d)	Days of operation
17	0.5	0.5	57
14	0.6	0.6	56
10	0.7	0.7	30
8	0.9	0.8	24
5	1.4	1.3	15

D. Analytical Procedure

Several parameters were measured accordance with methods described in Standard Methods for the Examination of Water and Wastewater [13]. The effluent from the reactor was sampled every 2 days for COD and every 1 week for VFA, alkalinity, TKN (ammonia), and gas production (composition). A water column was used to measure biogas production. The COD was measured using a DR 2010 spectrometer and COD reactor (HACH, USA) following the instructions for the HACH higher range test. The gas composition was measured using a GA 5000 Geotech gas analyser (GA5000, UK). The pH and temperature were also monitored daily using pH and temperature probes (HACH, Sension +pH1, USA). All tests were performed in duplicate to obtain a consistent average. All analyses were undertaken at a room temperature of 27±2°C.

III. RESULTS AND FINDINGS

Experiments was conducted successfully to investigate the performance of UAFF at reduced HRT and consequently to evaluate the biogas production and organic removal. In the beginning of the experiments, OLR was increased by decreasing the operating HRT. The UAFF reactor was thus operated at five different HRT of 17, 14, 10, 8 and 5 days. For each batch, the UAFF ran for 3 cycles until reaching steady state. Steady-state operation can be defined by stable gas production and constant COD values in the effluents [14]. Between each test, there was a break period in which the reactor was maintained with the previous HRT but no samples were taken and no monitoring was conducted.

A. pH Profile of UAFF

The pH is an essential factor to control during anaerobic digestion. It is known that all anaerobic digesters have an optimum pH in the range of 6.6 – 7.6 and that a pH below 6 affects the waste degradation and methane formation [15], although stability may be achieved in the formation of methane over a wider pH range (6.0 – 8.0). pH values below 6.0 and above 8.3 should be avoided, as they can inhibit the methane forming microorganism [16]. The pH variation in anaerobic digester at various hydraulic retention time are shown in Fig. 2.

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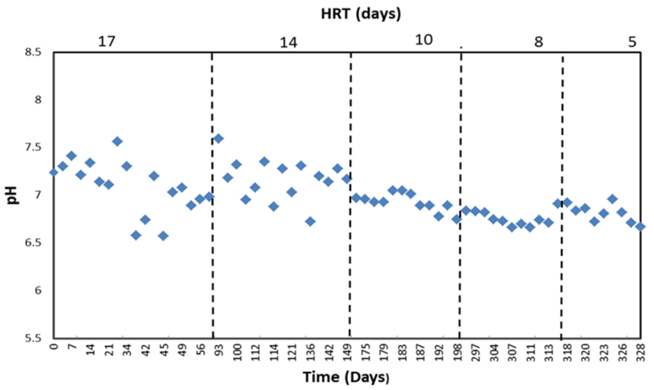

Fig. 2. pH profile of the UAFF at different HRT

The result shows that the pH in reactor decreased slowly with the reduction of HRT. The pH fluctuated at HRTs of 17 and 14 d. When entering an HRT of 10 , 8 and 5 d the pH generally decreased and then became constant due to the accumulation of acids. In all HRTs studied here, the pH remained above 6.0 and below 8 during the operating time, which indicated the bacteria adapted well to the HRT change and were not adversely affected by the pH reduction resulting from the reduced HRT.

B. COD Profile of UAFF

Fig. 3 depicts the total soluble COD removal efficiency and effluent COD concentration variant in the UAFF at reduced HRT over time. The total COD removal efficiency at 17 d of HRT was decreased from 99% to 98% with COD effluent concentration increased from 57 mg/L to 137.5 mg/L. At HRT of 14 d COD removal efficiency reduced further from 98% to 96% with COD effluent concentration increased from 129.5 mg/L to 214 mg/L. For HRT 10 and 8 days, removal efficiency fluctuated from 90% to 95% at the end of HRT 8 days with COD effluent concentration also fluctuated from 356 mg/L to 285.5 mg/L. As in the lowest HRT which was at HRT 5 days, removal efficiency reduced from 93% to 79.5% with the effluent concentration increased from 315 mg/L to 515 mg/L.

Reducing HRT cause the UAFF became less efficient in removing COD. This indicates that at higher OLR, the more COD in the reactor was composed of unused of volatile fatty acids. This also explained the VFA concentration accumulated in the reactor at HRT of 5 days up to 391 mg/L. The accumulation of COD in the reactor was a significant indicator of pre-acidification process due to low of HRT [15]. This results agrees with the trend observed by [6], who showed that when HRT reduced from 10 to 2.5 days with OLR increased from less than 2 to over 11 g/L.day and fluctuated at HRT of 2.5 days, only little change of removal efficiency occurred in anaerobic filter. In the other hands, [2] in his work achieved COD removal efficiency 97.6% at OLR of 0.91 kg/m3.d with constant HRT of 11.1 days and influent COD concentration 10 200 ± 1370 mg/L.

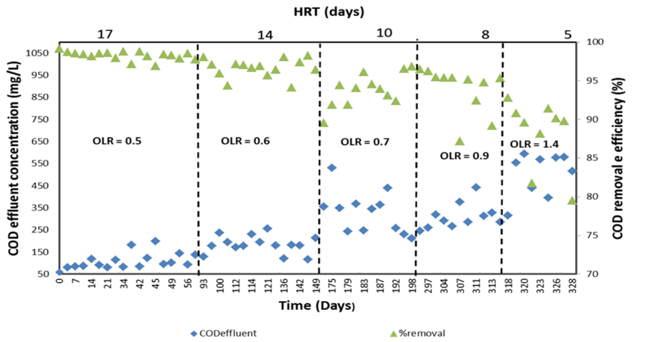

Fig. 3. Total COD removal (%) of the UAFF at reduced HRT

This proved that fixed film filter was efficient at low HRT and therefore a short HRT was not responsible for the drop in treatment efficiency. This also suggests that anaerobic filter is capable to stabilize its effluent quality. Moreover, low-strength soluble organic industry loading that have COD concentration in the range of 2000 – 20 000 mg/L can be treated when increased in retention time. due to the fact that the highly concentrated bacterial population of the filter could made the digestion process more stable even during significant variations in operating conditions and loadings [16].

C. VFA, Alkalinity, VFA-Alkalinity Ratio and Buffering Capacity

Of the many parameters, the best individual one to indicate the problem of unbalanced treatment is the volatile acids (VFA). The methane bacteria are responsible for destruction of VFAs, and if they become affected by adverse condition, their rate of utilization will slow down, and the volatile acid concentration will increase. Generally, high VFA concentrations in anaerobic processes cause the inhibition of methanogenesis [17]. Under conditions of overloading and in the presence of inhibitors, methanogenic activity cannot remove hydrogen and VFAs cumulated as quickly as they are produced. The result of the acids accumulation is pH depression which also inhibit the hydrolysis or acidogenesis phase. It has also been shown that, even when process pH is optimal, the accumulation of VFAs may contribute to a reduced rate of hydrolysis of the solid organic substrate [18]. Organic acids such as acetic, propionic, butyric and isobutyric acids are central to evaluating the performance of anaerobic digestion [19].

As in Fig. 4, shows the total VFA and alkalinity concentration. The total VFAs concentration increased as HRT decreased. During HRT 17 and 14 d VFAs concentration seems stabilized and increased slowly around 0.5 – 87.5 mg/L. When entering HRT of 10 d, the VFAs concentration suddenly drops slightly when reaching to 180.5 mg/L. VFAs concentration was then slightly increased and fluctuated at HRT 8 and 5 d from around 71 to 351 mg/L .

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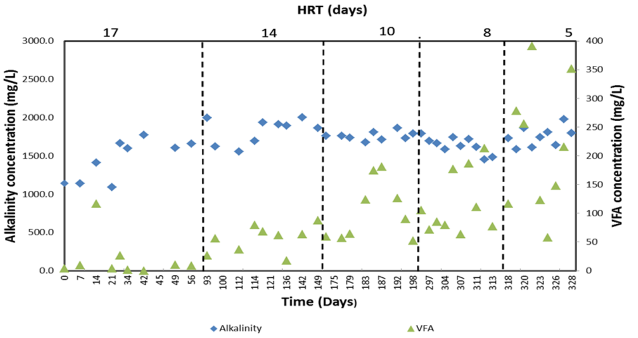

Fig. 4. Volatile acid and alkalinity profiles in the UAFF at various HRT

In the previous work, when total VFAs was recorded below 500 mg/L, it is a mark of stability performance of an ABR (treating highly concentrated industrial dye effluent with COD up to 4500 mg/L) [20]. Consequently, it can be concluded that UAFF operation (inlet COD of 5500 - 6500 mg/L) was quite stable since the effluent VFA was less than 400 mg/L throughout the experimental period (HRT 17 – 5 d).

Additionally, the alkalinity or buffering capacity of the water is another important parameter, as this affects the pH. The pH must be near neutral for satisfactory treatment, and this requires a bicarbonate alkalinity of at least 1500 mg/L for waste treatment in the presence of an atmosphere containing about 30% carbon dioxide. A higher alkalinity of 3000 to 4000 mg/L is more desirable, as it gives better cushion against a drop in pH resulting from excessive volatile acid increase [21].

As for alkalinity in UAFF (Fig. 3), it increased as the HRT decreased, from 1090 to 1998 mg/l during HRT 17 and 14 d. This may due to significant changes in the operational conditions. The alkalinity in the anaerobic digester for the HRT of 10, 8 and 5 d was practically constant (average 1713 mg/L) and still in the optimum range. Only in the start-up period was the alkalinity below the optimum range.

[22] also reported an increase in the alkalinity with the increasing OLR in the treatment of the wastewater of a poultry slaughterhouse. The operational conditions that result in an increase in the alkalinity include increased alkalinity loading (ammonium ions, amino acids, proteins and cationic polymers), the death of a large number of strict aerobic bacteria, resulting in the release of large quantities of amines, and decreased alkalinity destruction within the reactor. [23] reported that the VFA to alkalinity ratio should not exceed 0.5 to avoid system failure. Table V summarizes the VFA/Alkalinity ratio for all HRTs.

Table V: Buffering capacity of the UAFF at reduced HRT.

HRT, days	Buffering Capacity		
	pH	**Alkalinity (mg/L)**	**VFA/Alkalinity ratio**
17	7.09	1453	0.007
14	7.17	1830	0.030
10	6.93	1761	0.058
8	6.76	1637	0.080
5	6.81	1751	0.114

One of the key control parameter to ensure the well-being anaerobic digester system by assessing the increment of VFA that can be tolerated without an excessive drop in pH. Therefore, VFA-to-alkalinity ratio was estimated to enumerate the ability of the system's capability to cope with the rapid change of pH. A ratio of 0.07 – 0.08 is suggested as a good working ratio [16]. In this study, all of the ratios were remained below the maximum allowable limit, this explaining their ability to buffer against the changes in pH caused by the accumulation of VFA in the system.

D. Ammonia Removal

Fig. 5 depicts the ammonia (NH_3-N) concentration in the anaerobic digester for all HRTs. At HRT of 17 and 14 d, NH_3-N concentration were in the range of 50 – 100 mg/L with influent concentration was 47.6 mg/L. At HRT 10, the influent NH_3-N was increased to 71.96 mg/L and effluent concentration was increased to 86 – 100 mg/L but decreased to 69 mg/L. Influent concentration increased to 208 mg/L at HRT 8 and 5 d, but in effluent of HRT 8 d, NH_3-N was below the influent value which was in the range 205 – 113 mg/L. However, during HRT of 5 d, the effluent concentration value was above the influent concentration which was in the range of 234 – 258 mg/L.

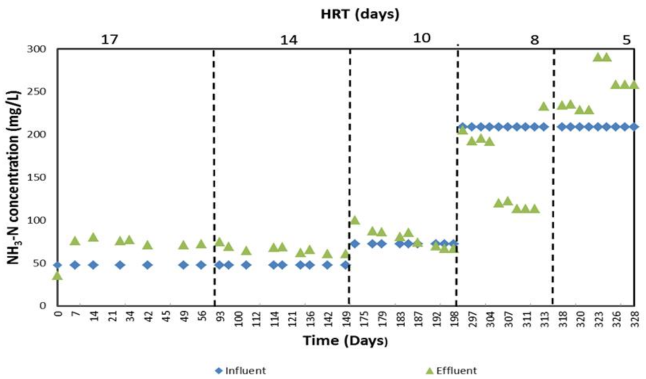

Fig. 5. Ammonia concentration in the influent and effluent of the UAFF at reduced HRT

Table VI listed the ammonia nitrogen concentrations which may have an adverse effect on anaerobic treatment [24]. If the concentration is between 1500 and 3000 mg/L and the pH is greater than 7.4 to 7.6, the ammonia gas concentration can become inhibitory. This condition is characterized by an increased in volatile acid concentration which tends to decreased the pH, temporary relieving the inhibitory condition. The volatile acid concentration here will then remain quite high unless the pH is depressed by some other means, such as by adding hydrochloric acid to maintain the pH between 7.0 and 7.2. When ammonia nitrogen concentration exceeds 3000 mg/L, then the ammonium ion itself becomes quite toxic regardless of pH and the process can be expected to fail. A wide variety of previous studies showed that a total ammonia nitrogen (TAN) concentration from 1.7 to 14 g/L caused a 50% reduction in methane production [25].

Table VI: Effect of Ammonia Nitrogen Concentration on Anaerobic Digestion.

Ammonia Nitrogen Concentration (mg/L)	Effect on Anaerobic Treatment
50 – 200	Beneficial
200 – 1000	No adverse effect
1500 – 3000	Inhibitory at higher pH values
Above 3000	Toxic

Several authors have found that the anaerobic fermentation of waste with a high concentration of ammonia was more easily inhibited and less stable at thermophilic temperatures than at mesophilic temperatures [26] and [27]. In this study, the temperature of the anaerobic reactor was kept between 28 and 35 °C. Although the ammonia concentration at a safe level, failing to maintain the pH within an appropriate range could cause reactor failure [20]. During the anaerobic digestion of liquid piggery manure which has pH 8, the VFAs accumulated to 316 mg/L. The adjustment of the pH to 7.4 led to the reutilization of VFAs and lowered the VFA concentration to 20 mg/L. The better performance at pH 7.4 has been attributed to the relief of the ammonia-induced inhibition at low pH [27].

E. Biogas Production Rate and Composition

Fig. 6 shows biogas production rate from UAFF at reduced HRT. The biogas generation increased as HRT reduced. From the figure, the biogas production rate achieved the lowest production at HRT 0f 17 days with the production rate range between 1 – 2 L/day. As HRTs were reduced further, from 14 to 8 days, the biogas production increased in the range 1 – 2.7 L/day for each HRT. Next, when entering to HRT of 5 days, the biogas increased and achieved the highest production rate in the range of 2.8 – 3 L/day. The higher OLR at shorter HRT was observed to increase the biogas production rate.

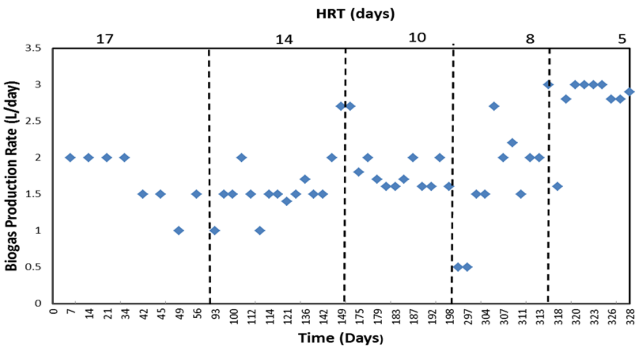

Fig. 6. Biogas production rate of the UAFF at different HRT

Generally, the biogas produced from a reactor consist of hydrogen and carbon dioxide, methane, hydrogen sulfide and oxygen. The only gas of economic value that is produced in anaerobic digester is methane. The methane production by composition systematically increased when the HRT was reduced from 17 to 5 d, where the highest methane production percentage obtained was 48.2% at HRT 5. It has been widely reported that the methane productivity increases with decreasing HRT, which is however expected in continuously operating systems without kinetic limitations.

Fig. 7 depicts the variation in the methane content through all of the HRTs.

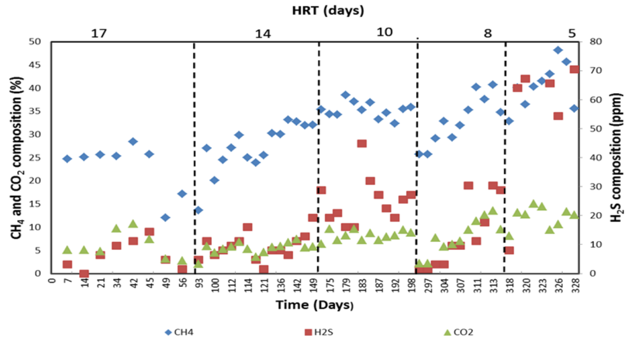

Fig. 7. Methane, CO_2 and H_2S composition of the UAFF at different HRT

This shows a clear trend of the microorganisms adapting to the new environment and the improved methanogenic activity of the biomass. During the start-up of the anaerobic treatment process, some methane formation is produced during the early stages. However, this is involved only from certain materials that are readily fermented to methane. Seeding process is really important as it helps specific methane formers to growth in reactor and fermented certain asid present. Methane production produced in stages and each stage represent the culmination of the growth a population of methane formers that are capable of fermenting one particular group of compounds. Without the benefit of this "seed" sludge, this process may take several weeks because the process is not completely operational until all groups of methane formers are finally established. This can be seen that on day 49, the methane was reduced to 12%, which shows the temporary inhibition of the methanogens inside the reactor. However, there is a quick recovery and improved methane content with the increasing OLR. Nevertheless, the methane production does not achieve the optimum composition which was in the range of 65 – 70% [27].

CO_2 percentage in the reactor also seems increasing as HRT reduced. This confirming that high methanogenic activity in the reactor system even at high OLR and short HRT. If the CO_2 fraction in the biogas increased above 30%, the acid concentration in the sludge increased and the pH drops below 7.0. At pH below 7.0, significant acid fermentation occurs [23]. Throughout the experiment period, CO_2 was below 30% as HRT reduced.

Hydrogen sulfide (H_2S) produced in the anaerobic digester is the most undesirable gas among other inorganic gases. If biogas contains too much H_2S, the gas may damage digester equipment. In this study, the highest H_2S value was 44 ppm which was equivalent to 0.0044% of the total biogas percentage. This value considered too small and UAFF was proved to be efficiently in working.

IV. CONCLUSION

From the experimental results it can be concluded that only a minor reduction in COD removal efficiency was observed when the reactor was operated at high feed flow rate

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(5 d HRT). The UAFF performance depends on a number of factors: HRT, OLR and the concentration of COD. Results showed stable performance in terms of pH, methane production and COD removal efficiency. Lower COD removal efficiency, at HRT 5 d (shorter HRT) was probably due to incomplete degradation of the more recalcitrant feed. In future research, it is suggested that the C/N ratio of the influent must be adjusted to optimize the methane production.

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