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Optimization of operation conditions for the start-up of a pilot-scale anaerobic biofilm digester treating leachate

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ABSTRACT

In solid waste management, treating putrid leachate is the most challenging part especially for Malaysia, which has hot and humid weather and raining season throughout the year. Leachate pollution has become a more serious problem these recent years as lack of proper treatment facilities at waste disposal sites affected the quality of water supply due to the penetration of leachate into the groundwater table and its discharge into the rivers. Anaerobic treatment has recently been mentioned by the Malaysian government as the most sustainable technology for waste treatment. Hence, the objective of this study is to optimize the operation conditions for the start-up of a pilot-scale anaerobic biofilm digester at UKM Biogas Site for leachate treatment. In this paper, the results of two separate preliminary operations of anaerobic digestion of leachate are presented. The first operation, conducted with 20-d HRT (daily feed 0.30 m^3/d) and pH adjustment, was halted after 35 d due to the hydraulic and organic overloads, resulting into system failure. The results were taken into account while commencing the second operation by using the buffering step where small amount of leachate was fed for a month (0.03 m^3/d for the first week and 0.06 m^3/d for the rest weeks), with no pH adjustment. This buffering step was conducted to enable the microbes to acclimatize to leachate's low pH and its high organic contents. This step was proven better as parameters observed (pH, total suspended solids, volatile suspended solids, chemical oxygen demand, NH_3-N, total volatile fatty acids) showed more consistent values than those of the first operation.

Keywords: Anaerobic digester; Pilot scale; Start-up operation; Leachate treatment

1. Introduction

Leachate is a liquid that has permeated through or been generated by degradation of waste including water that comes into contact with waste and is contaminated by its contents (organics, metals, salts and other soluble or suspended components and products of decomposition of the waste) [1]. The composition of leachate depends on waste types, disposal sites, weather (which controls moisture content and temperature), available oxygen, waste processing, toxicity [2,3] and other variables. For example, leachate from landfills are mostly mature leachate, depending on the age of the landfills it was collected from [4], while those collected in transfer station are fresh leachate. This is because the transfer station is a depot for the reception and aggregation of waste prior to its transport to landfills [1]. The leachate in transfer station is stored in closed storage tanks, making it more concentrated than landfills' ones which are heavily diluted due to being exposed to Malaysia's hot and raining climate throughout

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the years. The difference between mature and fresh leachate lies in their characteristics and pollutant values, which have proven lower for mature as compared with fresh leachate [4].

In Malaysia, leachate is usually collected in a leachate pond at open dumping sites [5], leachate collection lagoons at sanitary landfills [6] and leachate storage tanks at waste transfer stations. Unfortunately, most waste disposal sites are not installed with leachate treatment facilities, especially at open dumping sites [5]. One landfill that is fully equipped with leachate treatment system is the Bukit Tagar Sanitary Landfill (BTSL). However, the leachate treatment system at BTSL is costly and land intensive and therefore unsuitable to be implemented at other landfills and transfer stations throughout Malaysia. Furthermore, the open system of leachate ponds and lagoons in landfills is not sustainable due to the release of methane gas which is the by-product of anaerobic digestion process and also a powerful greenhouse gas [7]. A closed-system of anaerobic digestion, however, could be better for leachate treatment due to the low use of chemicals (for pH adjustment) and also the release of methane to the atmosphere could be avoided if collected and valorized in a combined heat and power installation for the simultaneous generation of heat and electricity [8].

There are a lot of treatment systems being used to treat leachate and the effectiveness of these systems depends on leachate's age (young, medium, old). For example, biological treatments (anaerobic and aerobic) show great performance in treating young leachate while adsorption and ion exchange systems are only effective for treating old or matured leachate. Nanofiltration and reverse osmosis are the most efficient in treating all kind of leachate but due to the expensive cost, these two systems are not even an option in the first place especially for developing countries [9]. Hence, biological treatment such as anaerobic digestion would be the best choice as it could treat leachate naturally (using ubiquitous microbial community), with lesser operation cost compared with aerobic treatment which has high operation cost due to the use of blower for aeration.

The application of anaerobic digestion technology for large-scale applications has been limited, essentially, because of the slow reaction rates and process variability. Slow reaction rates result in large digester volumes and consequently, greater costs and space requirements. Process variability results in non-steady energy generation which is a technical problem at large scale. These two limitations to conventional anaerobic processes have been overcome by high-rate anaerobic reactors, which employ cell immobilization techniques, such as granules and biofilms. More, moving bed biofilm processes allow microbes to grow on biofilm carriers that circulate freely in the reactor and are retained by screens at the outlets and inlets of reactor [10]. This avoids the washout of microbes which commonly happened in the conventional system, thus, retaining a group of microorganisms that become optimized for high-rate anaerobic degradation.

A majority of research conducted on the optimization of the anaerobic processes are mainly focused on the identification of microbial community dynamics [11–13] and development of pre-treatment methods in laboratory scales [14–16]. However, variations in the feed (e.g., severely low/high pH, high ammonia contents or toxic substances such as sulfide, heavy metals and salts organics) are often encountered that complicate performance comparison between lab-scale and pilot-scale testing. Table 1 shows the inhibitory values of substances that are commonly referred to as toxic to anaerobic digestion processes. High salt or inorganic (e.g., ammonia) concentrations, for example, could reduce cell viability and/or activity [17,18].

Hence, the objective of this research study is to optimize conditions for the operational start-up of a pilot-scale anaerobic biofilm digester (ABD) in treating young leachate collected from Kuala Lumpur Transfer Station, Malaysia. Most of the previous anaerobic treatments of leachate studies in Malaysia were performed as laboratory scale [19,20]. The results are largely unsuitable to predict scale-up performance in industry since the surroundings and the constructed systems between these two working environments are completely different. Furthermore, leachate is a feed source that imposes significant instability on anaerobic digestion processes. Hence, lab-scale work is rarely useful for evaluation at demonstration scale. As such, this research work presents data on the treatment of leachate at pilot scale using two separate start-up operations of a pilot-scale ABD. The first operation was conducted with 20-d HRT (daily feed 0.30 m^3/d) with pH adjustment, while the second operation was performed with two different HRTs continuously for a month with daily feed 0.03 m^3/d for a week and 0.06 m^3/d for the rest 3 weeks, with no pH adjustment.

During each operation, the ABD was seeded beforehand, with different seeding substrate so as to prepare the inoculums for the treatment process. There is no significant justification in choosing different seeding substrate, other than its availability in terms of distance (short distance from the project site) and financial limitation. The main parameters observed during these start-up operations are: pH, total suspended solids (TSS), volatile suspended solids

Table 1
Inhibitory concentrations of toxic substances for anaerobic digestion process

No.	Substances	Inhibitory concentration (mg/L)	Reference
1	Ammoniacal nitrogen	1,500–3,000	[21]
2	Heavy metals:		[17]
	Cuprum	40	
	Cadmium	20	
	Zinc	150	
	Nickel	10	
	Plumbum	340	
3	Salts (cation):		[21]
	Sodium	3,500–5,500	
	Potassium	2,500–4,500	
	Calcium	2,500–2,500	
	Magnesium	1,000–1,500	
4	Volatile fatty acids (total)	<1,000 (stable) 1,000–4,000 (intermediary) >4,000 (unstable)	[17]

(VSS), chemical oxygen demand (COD), ammonia-nitrogen (NH_3-N) and total volatile fatty acids (tVFA). pH and tVFA are the main indicators for anaerobic digestion process stability especially during the start-up. The monitoring of ammonia is significant since it usually accumulates in the tank and high value of it could be toxic for the ABD system. The COD reduction percentage will imply the system performance while TSS and VSS are monitored so as to know the concentration of suspended solids, an indicator for overall degradation performance [17].

2. Methodology

2.1. UKM biogas site

At UKM biogas site, the demonstration plant setup was constructed with one mini laboratory and a pilot-scale ABD system (Fig. 1). Fig. 2 shows the photograph of pilot-scale ABD system at UKM biogas site. The digester has an effective volume of almost 6 m^3 (5,950 L) and was filled with HDPE plastic medias for biofilm attachment (as shown in Fig. 2). As presented in Fig. 1, the digester is divided into two parts, with only 1-foot opening interconnecting both parts, so as to perceive whether Part A represents acidogenesis phase, while Part B methanogenesis phase. During the feeding process, the contents inside ABD were mixed thoroughly using the recycling pump. Every inlet and outlet was installed with stainless steel sieves to ensure the HDPE plastic media remained inside the digester.

2.2. Operation of the pilot-scale anaerobic biofilm digester system

2.2.1. First operation on May 2014

During the first operation, the seeding process for the pilot-scale ABD was executed by mixing palm oil mill sludge and raw leachate with no adjustment to pH. Raw leachate was collected from Taman Beringin Transfer Station owned by Kuala Lumpur City Hall located at Jinjang Utara, Kuala Lumpur (KL), whereas the sludge was obtained from the anaerobic digester treating palm oil mill effluent at Sime Darby Plantation, in Carey Island, Klang, Selangor. The ABD was filled with the anaerobic sludge and leachate at equal volume. After almost 2 weeks after inoculation of the seed culture, leachate treatment at 20-d HRT with pH adjustment was carried out by feeding the ABD system leachate and sodium hydroxide with volume ratio of 1.5:1, respectively, within 35 d. pH was adjusted to between 6.6 and 7.0 [22]. Effluent leaving the overflow pipe (Fig. 1; sampling point B) was collected daily in the sludge thickener for sampling. The effluent inside the thickener was first stirred and then collected in the HDPE sampling bottle. Sample storage was done using the guideline from EPA [23] until removed for testing.

2.2.2. Second operation on October 2014

The second operation used wastewater, taken from Indah Water Konsortium treatment plant in Subang Jaya, Selangor, as the sole seeding substrate. After almost 3 weeks of seeding

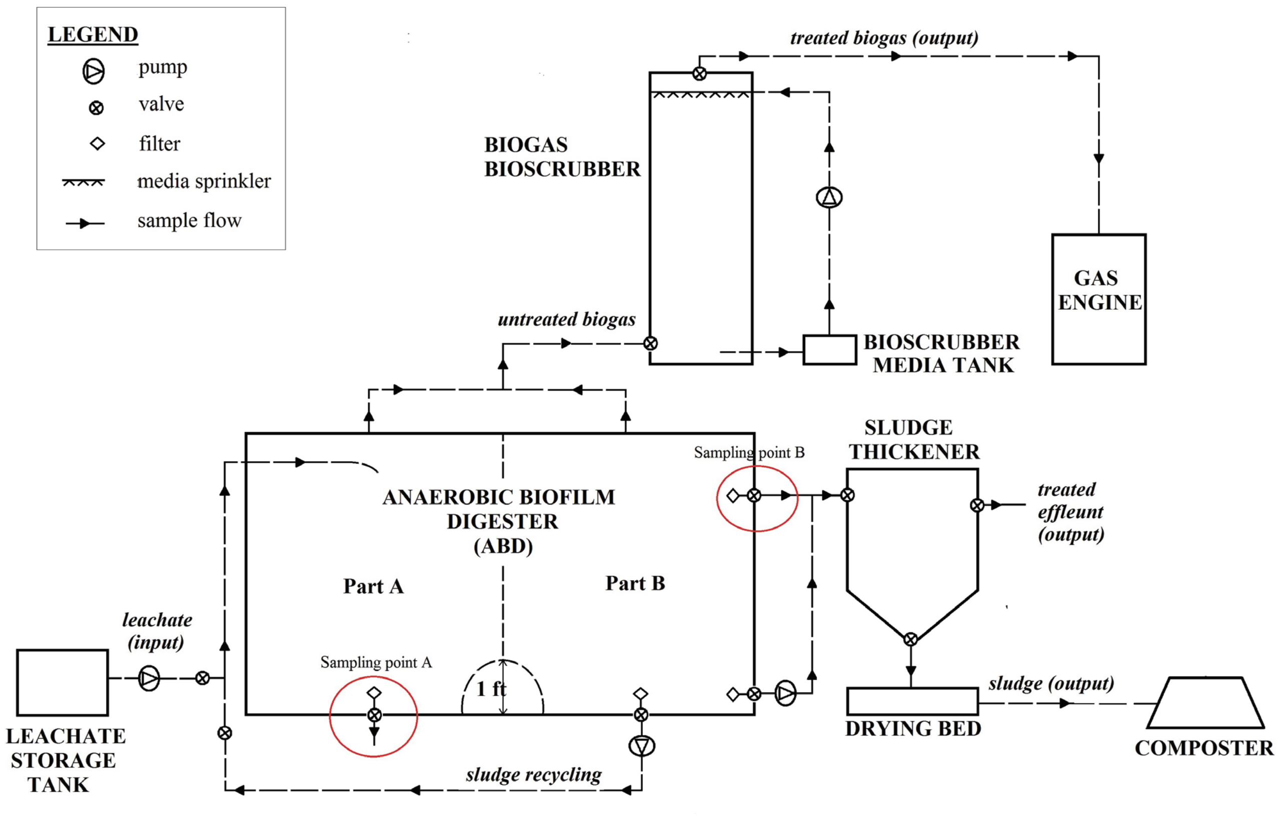

Fig. 1. Schematic drawing of a complete pilot-scale ABD system.

process, the ABD system was fed with the raw leachate in small amount of 0.03 m^3/d for 198-d HRT until the next feed was increased to 0.06 m^3/d for 99-d HRT. Since the leachate fed was small in amount, the sampling technique was executed by taking the samples from both Part A and Part B of ABD (Fig. 1; sampling point A and B), in order to see the difference in parameters value especially for pH and tVFA. There is no pH adjustment for both seeding and feeding processes.

2.3. Laboratory analysis

Parameters analyzed for the leachate characteristics and monitoring during the operations were pH, COD, TSS, VSS and ammonia-nitrogen. Total volatile fatty acid was monitored for system stability during second operations only. The methodology used for samples analyses was in accordance with the Standard Method for the Examination of Water and Wastewater [24], except for COD and tVFA which were determined using reactor digestion method (HACH, COD High Range, DR 6000 spectrophotometer) and esterification method (HACH, Method 8196, DR 6000 spectrophotometer), respectively. The tests were performed in duplicates to obtain a consistent average. All analyses were undertaken at room temperature of 25°C ± 2°C.

3. Results and discussion

3.1. Leachate characteristics

Table 2 showed the characteristics of raw leachate from Taman Beringin Transfer Station which was used as treatment substrate throughout the operations. The low pH of leachate from this transfer station is in accordance with the range of pH value (<6.5) for leachate from young age landfill which has 80% of volatile fatty acids as its organic compounds [9]. This is further proven when transfer station leachate's COD showed a high value of 35,895 ± 1,788 mg/L, indicating a highly polluted sample characteristic. VFA for leachate sample cannot be determined using the esterification method from HACH due to the over range value.

Table 2
Characteristics of leachate from Taman Beringin Transfer Station

No.	Parameter	Value (Avg ± SD)
1	pH	4.44 ± 0.17
2	Total suspended solids (TSS) (mg/L)	16,750 ± 6,435
3	Volatile suspended solids (VSS) (mg/L)	14,550 ± 5,586
4	Chemical oxygen demand (COD) (mg/L)	35,895 ± 1,788
5	Ammonia-nitrogen (NH_3-N) (mg/L)	447 ± 68

Note: The average (Avg) and standard deviation (SD) values of parameters were derived from the test results of leachate characterization performed for three different loading during the treatment operations.

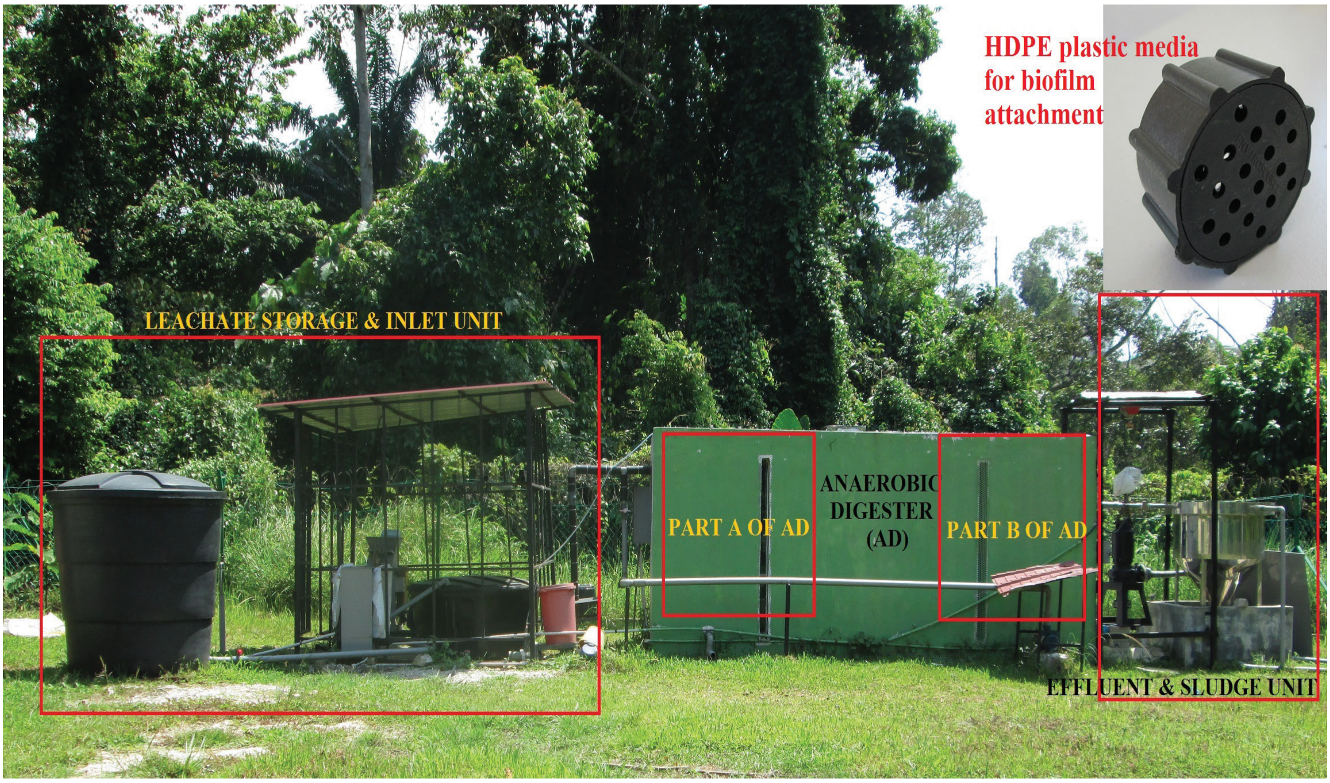

Fig. 2. Pilot-scale ABD system at UKM biogas site.

3.2. First operation

To correct for the low pH of raw leachate (4.44 ± 0.17), pH adjustment was done by injecting sodium hydroxide (NaOH) into the ABD throughout the feeding process. Fig. 3 shows the pH values of the digester throughout the 35-d feeding process. Initially, various concentrations of NaOH were injected to determine the suitable concentrations to be used. However, as shown in Fig. 3, from day 1 to 5, there was a sudden drop due to the insufficient NaOH concentration injected (0.04–0.06 M). Hence, NaOH concentration was increased to a range of 0.3–0.5 M. Since there was a rapid increase of pH value, a lower NaOH concentration of 0.2 M was selected as the fixed NaOH concentration injected to stabilize the ABD, starting at day 16 till day 35.

Tests for COD, TSS, VSS and NH_3-N were performed beginning on day 16. Fig. 4 shows the graph of TSS vs. VSS which presented a significant decrease on day 20. On day 32, TSS and VSS values are parallel with each other showing a death phase and at the same time there is sudden drop in the digester pH. This situation occurred due to hydraulic overload. Hydraulic overload occurs when the volume of effluent discharged is high, leading to the washout of microbes. Washout could happen when microbes are not able to grow and attached on the biofilm carriers for the use of treatment [17]. Other than that, the high organic content leachate could cause organic overload (an occurrence when the amount of organic matters fed to the system exceeds the total degradation capacity by the microbes [17]) to the ABD system. This is further proven when the ABD system showed a low COD reduction value of 34% ± 5% (Fig. 5). Fig. 6 shows that the NH_3-N values in the digester are within the safe range around 400–700 mg NH_3-N/L. Ammonia is produced from the mineralization of organic nitrogen during the deamination of proteins and amino acids in AD [19]. Ammonia toxicity can be avoided if the digester pH is within the optimum range of 6.6–7.6 [22] and NH_3-N concentration within the range of 200–1,000 mg/L [21].

3.3. Second operation

The first operation showed that by commencing the ABD system with low HRT (high feed rate), it would cause hydraulic and organic overloads. This is because short HRT could abate the multiplication of anaerobic microbes especially methanogens, which has a slower relative proliferation rate, making their concentration decline and eventually washed out of system [17,25]. Hence, the second operation

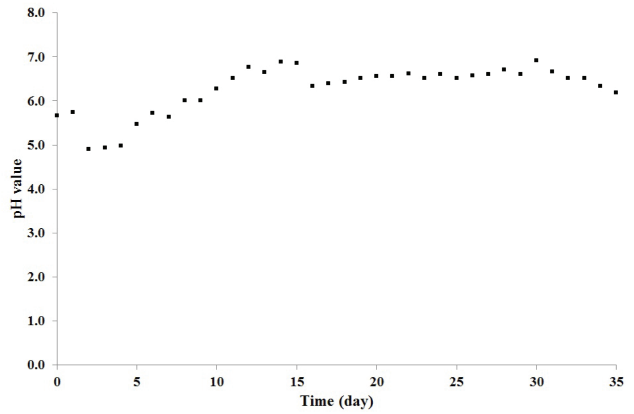

Fig. 3. pH values throughout the feeding process of pilot-scale ABD (first operation).

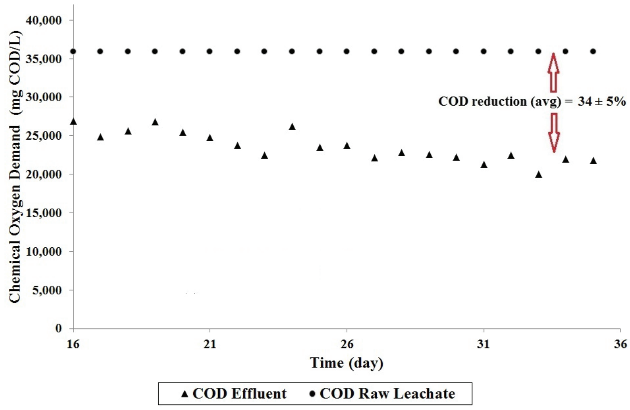

Fig. 5. COD values from day 16 to day 35 in the pilot-scale ABD (first operation).

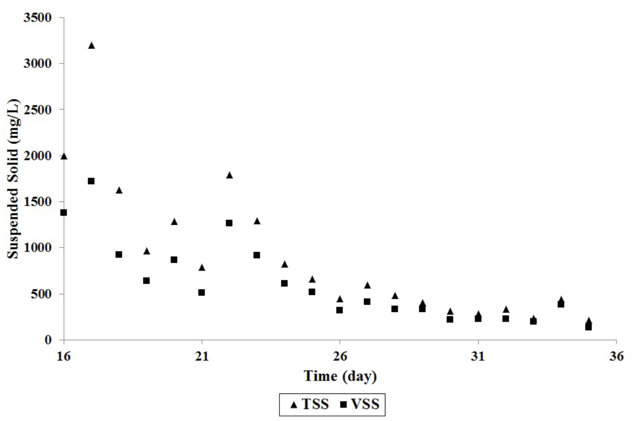

Fig. 4. TSS and VSS values from day 16 to day 35 during feeding process of pilot-scale ABD (first operation).

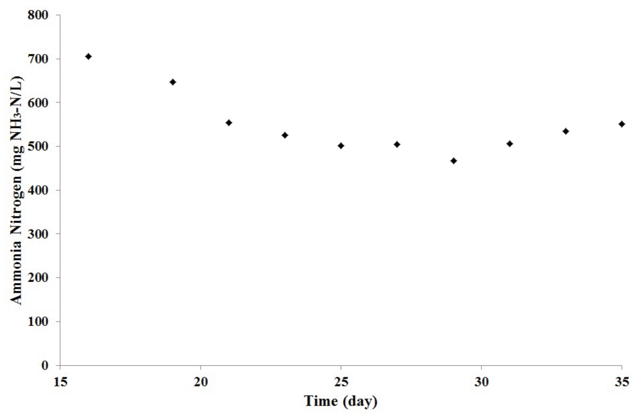

Fig. 6. NH_3-N values from day 16 to day 35 in the pilot-scale ABD (first operation).

was conducted differently by focusing on how to stabilize the system through microbial acclimatization, without involving the chemically induced pH adjustment step. By feeding the digester with 0.03 m^3/d for a week and 0.06 m^3/d for 3 weeks, respectively, this small-amount feeding acted as buffering step to stabilize the pH for both Part A (referred as Tank A) and Part B (referred as Tank B) of ABD system (Fig. 1). Initially, pH values (Fig. 7) for both Tanks A and B decreased during 0.03 m^3/d feed but when the feeding rate was increased to 0.06 m^3/d, pH values started to improve and stayed within the optimum range of 7–8 [26] throughout the operation.

This buffering step also gives time to the anaerobic microbes to steadily grow and proliferate, increasing their concentration inside the system which was shown by the consistent values of suspended solids (TSS and VSS) for both Tanks A and B (Figs. 8 and 9). The sampling point for Tank A is at the lower part of the digester, while the sampling point for Tank B is at the outlet for effluent discharge, hence, explaining the huge difference of suspended solid values between Tank A and Tank B. The suspended solid value for Tank B showed a sudden decrease during feeding rate 0.03 m^3/d. This was likely due to the low feeding rate which was not sufficient for the microbes to grow and proliferate.

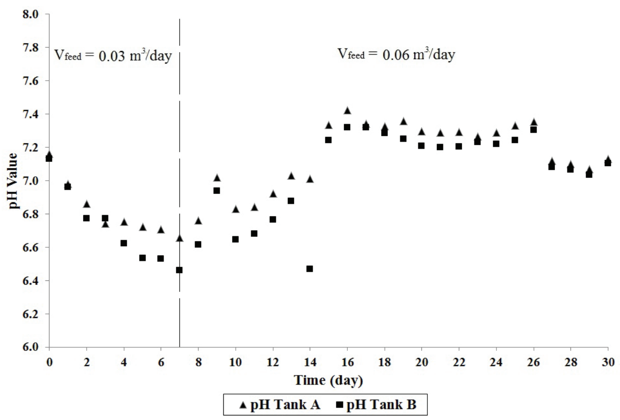

Fig. 7. pH values throughout the 30-d feeding process of pilot-scale ABD (second operation).

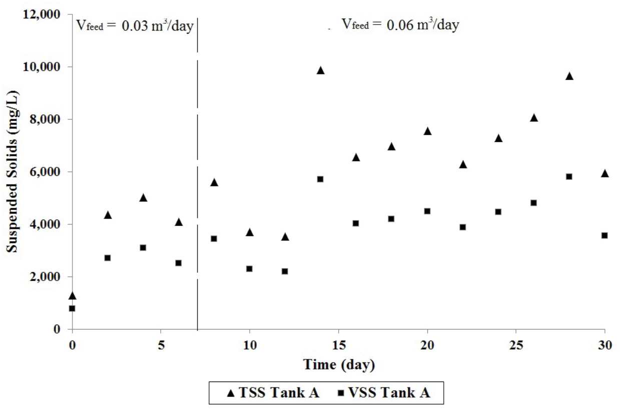

Fig. 8. TSS and VSS values for Tank A during feeding process of pilot-scale ABD (second operation).

When the feed rate was increased, the suspended solid values for both Tanks A and B steadily went up. The COD value for this second operation (Fig. 10) showed a really high reduction percentage of 97% ± 1% while the value range of ammonia (Fig. 11) is around 100–300 mg/L, two times lower than the first operation.

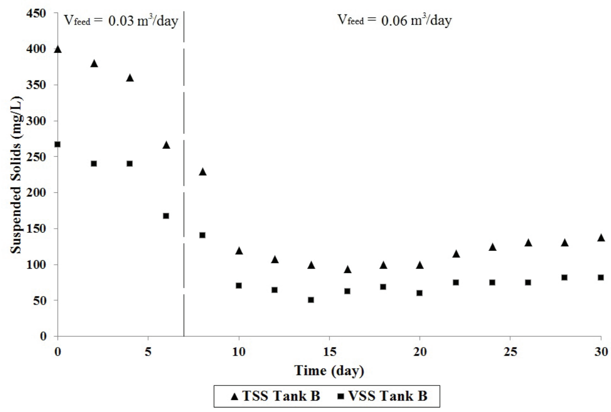

Fig. 9. TSS and VSS values for Tank B during feeding process of pilot-scale ABD (second operation).

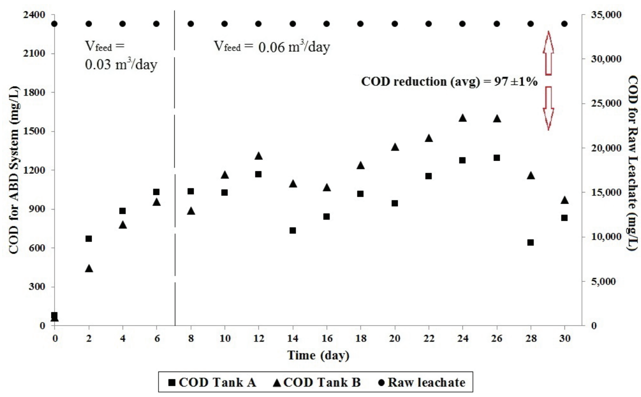

Fig. 10. COD values in the pilot-scale ABD (second operation).

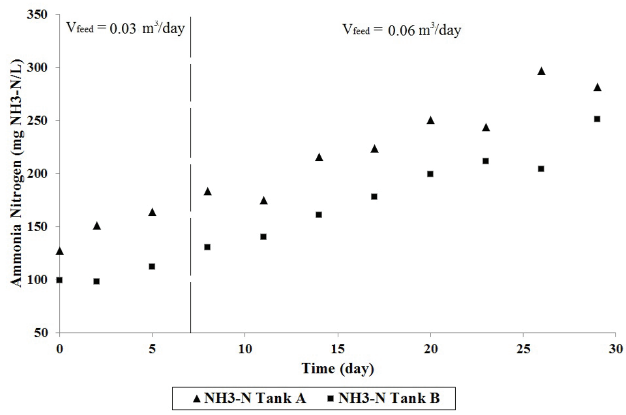

Fig. 11. NH_3-N values throughout the 30-d feeding process of pilot-scale ABD (second operation).

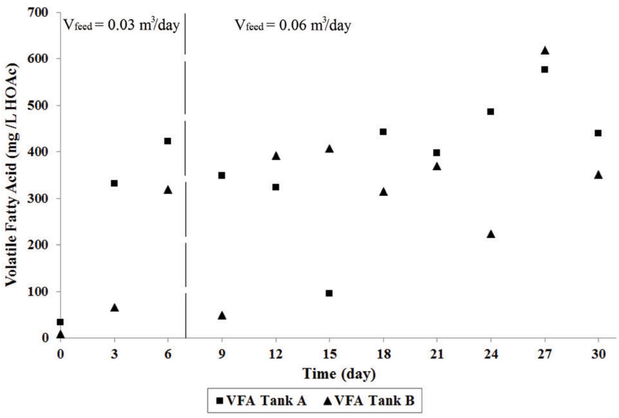

Fig. 12. Total VFA values throughout the 30-d feeding process of pilot-scale ABD (second operation).

For this second operation, total volatile fatty acid was determined to perceive the condition of two-part ABD system whether Tank A represented acidogenesis phase and Tank B methanogenesis phase. In addition, tVFA, presented as milligram acetic acid per litre, was measured to monitor the stability of ABD system based on the stability limitation unit shown in Table 1. As presented in Fig. 12, the measured tVFA values for both Parts A and B are ranged below 1,000 mg/L, indicating a stable anaerobic digestion system. Furthermore, throughout operation, tVFA for Tank A is mostly higher, signifying its condition as more acidogenic compared with Tank B and it is further proven as the pH value for Tank A is lower than Tank B (Fig. 7).

4. Conclusion

Leachate is a complex substrate to treat due to its severely low pH value and high organic and recalcitrant contents. However, the findings from these two separate start-up operations of anaerobic digestion of leachate using the high-rate digester (the use of HDPE media plastic as carrier for biofilm) showed that leachate treatment could be performed and acclimatization of microorganisms played significant role in its commencement. This is because, lower HRT (high feeding rate) could cause hydraulic and organic overloads, preventing the microbes to adapt and grow on the biofilm carriers for the use of treatment and eventually causing system failure. However, the problems from the first operation were tackled with the buffering step, which is carried out in the second operation, by feeding the system with lower feeding rate, allowing the microbes to acclimatize with the low pH and high organic content leachate steadily. This technique is proven to be better by looking at ABD system's performance in producing higher percentage of COD reduction (97% ± 1%) in second operation, compared with the first one (34% ± 5%). From the results, it is proposed that the low feeding rate with no pH adjustment enabled the microorganisms to acclimatize to the leachate characteristics and steadily proliferate with the increase in feed rate. Therefore, continuation of this research study should be done by monitoring more parameters to identify the best operation conditions, to get an efficient and optimized pilot-scale moving bed anaerobic digester system for the treatment of leachate in Malaysia.

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