THE EFFECT OF HYDRAULIC RETENTION TIME IN MUNICIPAL SOLID WASTE LANDFILL LEACHATE TREATMENT USING UASB REACTOR

Mohd. Izziuddin AB. MALEK, See Toh Mun YEE, Noorfaezah HUSNON and Md. Ghazaly SHAABAN

Department of Civil Engineering, Faculty of Engineering, Universiti Malaya, 50603 Kuala Lumpur, Malaysia

ABSTRACT

The treatability of municipal solid waste (MSW) landfill leachate using upflow anaerobic sludge blanket (UASB) was investigated. Leachate samples were collected from Jeram landfill and its characteristics were studied. Among the parameters concerned were the BOD_5, COD, SS, pH, ammoniacal nitrogen, alkalinity ($CaCO_3$), chloride, phosphate, and metals (sodium, magnesium, potassium, calcium, chromium, manganese, iron, nickel, copper, zinc, lead and cadmium). The BOD_5/COD ratio obtained was 0.70. Leachate samples were then being treated in UASB reactor with start-up hydraulic retention time (HRT) of 36 hours for two weeks. To ensure the granular formation initiated, variables such as substrate and environmental factors were controlled accordingly to ensure optimum operating conditions. Treatment of leachate were carried out by reducing the initial HRT 36 hours by 8 hours gradually with each reduction to last for a week (36, 28, 20 and 12 hours). The effect of HRT variation in UASB system performance in leachate treatment in COD and TSS removal was then analyzed.

INTRODUCTION

Landfill Leachate

General interpretation of leachate can be defined as liquid that leaches from a waste depository, whereby its composition varies widely with the age of the waste being deposited, the type of waste being disposed and the amount of compaction applied to the waste (Komilis *et al.*, 1999). Landfill leachate is highly variable and inconsistent throughout the world. The landfill leachate produced in younger landfills has substantial amount of volatile fatty acids (VFA) due to the acid phase fermentation. On the other hand, older landfill leachate has organics portions which are mainly humic and fulvic-like fractions (Kulikowska and Klimiuk, 2007). Leachate is likely to contain various types of pollutants which are formed by means of physical, hydrolytic and fermentative process, thus contains a high concentration of organic matter, inorganic ions and heavy metals (Al- Yaqout and Hamoda, 2003). The nature of landfill leachate forbid to be discharged directly to the environment due to its contents which dangerously causing health and environmental hazards.

Leachate Treatment

The landfill leachate needs to be treated accordingly to the standards before being discharged to the environment. Currently, leachate treatment can be classified into two major groups which are the conventional treatments and the new treatments. Conventional treatments encompass of leachate transfer, leachate recycle, biological treatment including aerobic and anaerobic processes, physical/chemical treatment involving flotation, coagulation-flocculation processes, chemical precipitation, adsorption, chemical oxidation and air stripping (Renou et al., 2008). As for the new leachate treatments, advance filtration process such as the microfiltration, ultrafiltration, nanofiltration and reverse osmosis are the main membrane processes applied in landfill leachate treatment.

In many parts of the world, the conventional treatment of landfill leachate still widely practiced. This is due to the perception of conventional biological treatments and physico-chemical methods are still being considered as the most appropriate technology for manipulation and management of high strength effluents like landfill leachate (Renou *et al.*, 2008). Treating young leachate with biological methods can yield a substantial performance in reducing the COD, NH_3-N and heavy metals. While for mature landfill leachate, physico-chemical treatments will act as a polishing step for biological treatment whereby it removes organic refractory substances. However, the conventional methods of leachate treatment have drawbacks. One of the major downsides which to be specifically, it become inefficient for nowadays leachate whereby landfills in most countries has come to its age and more stabilized leachate being produced. The conventional biological and physico-chemical treatments are unable to meet the level of purification needed to reduce the negative environmental impacts of this stabilized leachate. Problems associated with biological treatment, especially in suspended growth systems are the occurrence of sludge bulking, washout of nitrifying biomass and higher production of waste sludge (Tay *et al.*, 2006). Other shortcoming of conventional method is the requirement of large blueprint for a treatment plant. With the current availability of land, space become more limited than in 1970s or 1980s thus increase the total cost to construct one due to high price of land.

Upflow Anaerobic Sludge Blanket

The up-flow anaerobic sludge blanket (UASB) was first introduced in 1979 to treat methanol by G. Lettinga (Tay *et al.*, 2006). This modern anaerobic biological treatment can treat at high efficiency, which can handle high volumetric loading rate than other anaerobic treatment. Other advantages include low operating costs, compact reactor design, production of energy in form of methane gas, low sludge production (Tay *et al.*, 2006), short hydraulic retention time and has a low energy requirement (Najafpour *et al.*, 2006). The UASB reactor will perform well in temperatures exceeding 20°C, which is suitable in tropical countries such as Malaysia. A typical UASB reactor would be plug-flow type, whereby the influent is introduced at the bottom of the reactor and flow upwards through the outlet. A three-phase separator is placed at the top of the reactor to separate gas from the liquid phase and sludge from the water phase. In other words, it prevents sludge washout. The UASB system also comes with some flaws. One major problem is the slow start-up period, which could take several months to develop the multi functional sludge granules. However modifications can be made to outcome the deficiency by controlling the hydraulic retention time and the amount of substrate feed into the reactor. Other than that, the introduction of cations and polymers can also speed up granulation process.

Other kinds of leachate treatment whether conventional or advance treatment processes will simply involve high operation and maintenance costs. Conventional biological-physical-chemical processes require large plant area while advance treatment such as the reverse osmosis would have some problems of incomplete removal of heavy metals at low concentration, high energy consumption and generation of toxic sludge (Tay *et al.*, 2006). In this study, the UASB is expected to perform well in treating the municipal solid waste landfill leachate. The advantageous of UASB show the ability of this method to treat leachate. The effect of various hydraulic retention time in leachate treatment performance was studied. Two main parameters were involved; COD and TSS.

MATERIALS AND METHODS

Leachate Feed

Leachate samples were collected using grab method by using pail. A minimum of five different spots at landfill leachate pond were used as sampling point to ensure homogeneity of leachate samples. Collected leachate samples were then transferred into plastic bottle and then were stored inside cold room with a temperature of 4°C. This is to ensure the validity of samplings for experiments.

Leachate samples were obtained from the Jeram Sanitary Landfill which is located in Jeram County, Selangor. The landfill is managed by Worldwide Landfills Sdn. Bhd. with just above one year of operation. The Jeram Sanitary Landfill was constructed on 160 acre of land and was surrounded by oil-palm plantations which act as the buffer zone. It receives 1500 to 2000 tonnes of waste daily.

Sludge Preparation

The sludge sample was also taken from Jeram Sanitary Landfill as to ensure more stabilized performance of UASB reactor due to similar origin with the leachate samples. The sludge was tested for its total suspended solids and volatile suspended solids. The value of mixed liquid volatile suspended solids (MLVSS) was then obtained to provide the organic loading rate of 0.1 kg COD/ kg MLVSS day^{-1}. The Mixed liquor suspended solids (MLSS) selected for the system was 10000 mg/L. Total solids concentration of sludge is 34780 mg/L. Amount of sludge needed is:

$$\frac{\text{Volume of reactor x MLSS}}{\text{Total solid concentration of sludge}} = \frac{18\text{L x }10000\text{ mg/L}}{34780\text{ mg/L}} = 5.2\text{ L}$$

Therefore, 5.2 liters of sludge is pumped into the reactor and left to settle for 24 hours.

Equipment

Standard equipment was used for BOD_5 test method 5210. Standard equipment was also used for COD test method 5220 using reflux. Vacuum pump GAST model was used in suspended solid test (method 2540). pH and alkalinity measurements were carried out using Hanna Instruments HI 221 model (method 4500-H^- and method 2320 respectively). Phosphate was measured using HITACHI spectrometer (method 4500-P) while ammoniacal nitrogen was measured using KJELTEC SYSTEM 1002 Distilling Unit (4500-NH_3). All metals were tested and measured using Inductively Coupled Plasma-Optical Emissions Spectrometer (ICP-OES), USEPA SW-846 method 6020. The Lovibond 2000 Comparator was used for chloride test. MasterFlex peristaltic pump was used to pump the leachate into the reactor.

Upflow Anaerobic Sludge Blanket (UASB) Reactor

In this experiment, a laboratory-scale rectangular UASB was used. The reactor has an operational volume of 18 liters of working volume with dimensions of 110 cm in height, 11 cm in width and 24 cm of gas-solid separator. The UASB reactor was operated in room temperature between 26°C to 32°C. Leachate entered through the bottom of the reactor by peristaltic pump. **Figure 1** Shows a typical UASB experimental setup.

Experimental Procedure

The digester was fed with 5.2 liters of sludge and the sludge was allowed to stabilize for 24 hours for acclimatization. After 24 hours, the digester was fed with diluted leachate substrate (3000 mg COD/ L) at the hydraulic retention time of 36 hours (1.5 days) for two weeks.

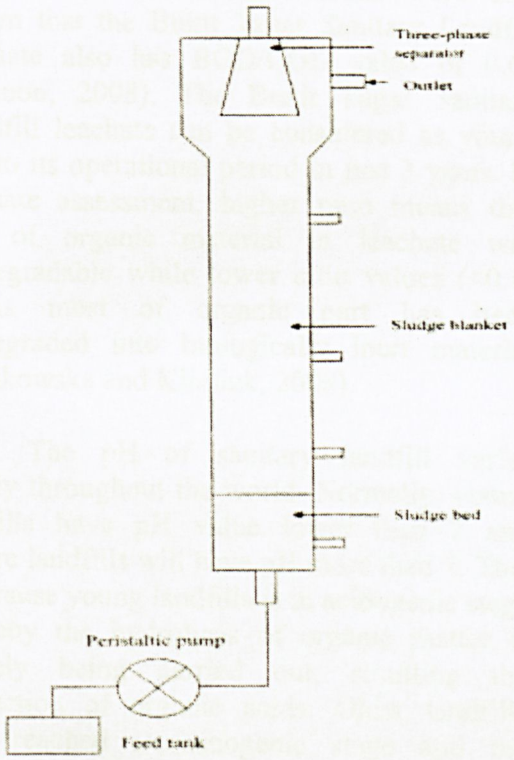

Figure 1: UASB experimental setup.

During start-up period, glucose water was added to improve the pace of granulation process. The addition of glucose water was continuously being carried out for two weeks until the sludge stabilized. After two weeks of start-up period, the initial HRT of 36 hours was reduced by 8 hours gradually with each reduction to last for a week (36, 28, 20 and 12 hours). Therefore, the total number of weeks after stabilization is four and during this period, alkalinity and pH were being monitored and maintained closely in range of 7 to 8.

Samples were collected from the intake and the outlet of the reactor were then tested for its COD, TSS, pH and alkalinity. The tests were done according to the Standard Methods 18th edition 1992 – for examination of water and wastewater (APHA, 1992). The frequency of leachate samples collection was three times a week for COD, alkalinity, and TSS.

RESULTS AND DISCUSSION

Leachate Samples Analysis

From the experiments, results have shown that the Jeram Sanitary Landfill (JSL) leachate characteristics as follows:

Table 1: General composition of JSL leachate (Husnon, 2008)

Parameter	(mg/L) except pH
BOD_5	30600
COD	43720
Suspended solids	225
Alkalinity ($CaCO_3$)	6900
Ammoniacal – N	448
pH	7.99
Chloride	<0.1
Phosphate	<0.009

Table 2: Metals content in Jeram Sanitary Landfill (JSL) leachate (Husnon, 2008)

Metals	(mg/L)
Na	0
Mg	192
K	901
Ca	52.6
Cr	-
Mn	-
Fe	3.85
Ni	-
Cu	-
Zn	-
Pb	-
Cd	-

Based on the results shown in **Table 1**, obviously the leachate sample can be classified as young leachate. The value of BOD_5 and COD were high (30600 mg/L and 43720 mg/L respectively) which result BOD/COD value equals to 0.7. The results also strongly agree with the time of construction of the landfill which was in February 2007, which means the landfill site is just almost one and a half year old. The landfill receives mixed municipal solid waste which mainly consist of food and household waste. Similar results were also shown that the Bukit Tagar Sanitary Landfill leachate also has BOD/COD value of 0.65 (Husnon, 2008). The Bukit Tagar Sanitary Landfill leachate can be considered as young due to its operational period in just 3 years. In leachate assessment, higher ratio means that part of organic material in leachate was biodegradable while lower ratio values (<0.1) means most of organic part has been biodegraded into biologically inert material (Kulikowska and Klimiuk, 2008).

The pH of sanitary landfill varies widely throughout the world. Normally, young landfills have pH value lower than 7 and mature landfills will have pH more than 7. This is because young landfills is in acidogenic stage whereby the hydrolysis of organic matter is actively being carried out, resulting the production of organic acids. Older landfills have reached methanogenic stage and the degradation process has slowed down. However, in this case, the JSL leachate has a pH value of 7.99 and still can be considered as suitable for its age. There is also literature stated that young landfills in China and Hongkong have varied pH from 7.8 to 9.0 (Renou et al., 2008). Husnon (2008) has also detected that the Bukit Tagar Sanitary Landfill leachate was 8.65. Although the landfill has been in operation for three years (longer than JSL), the leachate was still in young leachate category.

As for metal contents (**Table 2**), it seems that the JSL yields low concentrations of heavy metals. This is due to its age whereby the leachate produced was young and acidogenic. Probably a high degree of metal solubilization occurs in the leachate as a result of low pH (Kulikowska and Klimiuk, 2008).

Other than that, the concentration of suspended solids detected was low as compared to other young landfills. Normally, older landfills will have lower concentration of suspended solids. The JSL leachate yields low concentration of suspended solids probably due to early washout of solids by tropical rain.

Leachate Treatment

The UASB reactor was continuously fed with leachate for 28 days using peristaltic pump. pH in the reactor was maintained at range of 7.0 to 8.0 while alkalinity of the system was in the range of 2000 mg/L to 4000 mg/L by adding potassium hydrogen bicarbonate. As for MLSS, it was provided in concentration of 10000 mg/L to the reactor. Since the raw COD is too high for start-up, the COD was diluted to 3000 mg/L.

At the end of HRT 36 hours, highest COD removal was detected as much as 70.3%. However, the average value of COD removal was 61.7%. As for the HRT of 28 hours, COD removal was 68.5% and averaging 56.4%. At HRT 20 hours, the highest COD removal was 69% and averaging 59.9%. Finally, at HRT 12 hours, the highest COD removal achieved was 65.7% which averaging 57.7%. The COD removal at HRT 12 hours seems to be the lowest of all HRTs. All the data is shown in **Table 3.**

Table 3: COD removal during experimental study where HRT was shortened

Test	Day	HRT(hrs)	pH	% removal
1	4	36	7.88	50.0
2	6	36	7.90	64.9
3	8	36	7.60	70.3
4	10	28	7.60	43.6
5	12	28	7.80	57.1
6	14	28	7.40	68.5
7	17	20	7.50	46.0
8	19	20	8.00	64.7
9	21	20	7.80	69.0
10	24	12	7.40	47.1
11	26	12	7.60	60.4
12	28	12	7.90	65.7

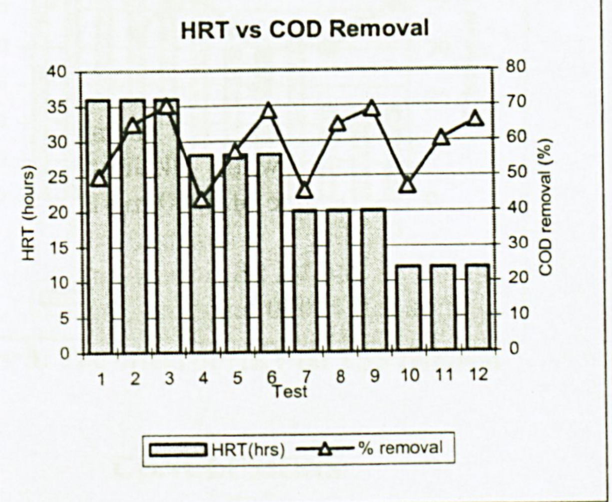

Figure 2: Effect of HRT on COD removal

According to **Figure 2**, it is shown that the removal rate fluctuates at each change of HRT. There is similarity of trends in COD removal all HRT started from 40%-50% removal in the first test and ended up with 60%-70% in the third test of the week. In this case, it tells us that even though the amount of HRT is different from one another, it can still achieve a considerable performance in COD removal from leachate if it been given longer time to treat. This is probably due to longer contacting time of the sludge with the substrate (leachate), which enables the microorganisms in the sludge treat take up more food from the leachate. It seems that the HRT of 36 hours produced the best result with 70.3% of COD removal at the end of the week. However, longer period of HRT (more than a week) is needed to determine the exact removal rate of COD by different HRTs so that the selection of suitable HRT can be made to treat leachate effectively.

The effect of HRT on removal of TSS in leachate was also being studied. **Table 4** and **Figure 3** shows TSS removal trend depending on various HRTs. Generally, the performance begins to drop as the HRT being reduced. It is found that HRT 36 hours produced highest removal value of 49.7%. The average removal value was 42.88%. HRT 20 hours had the lowest TSS removal rate of 28.6% with average removal rate of 31.1 %.

Table 4: TSS removal during experimental study where HRT was shortened

Test	Day	HRT (hrs)	% removal
1	4	36	34.5
2	6	36	44.4
3	8	36	49.7
4	10	28	33.3
5	12	28	38.2
6	14	28	40.0
7	17	20	33.9
8	19	20	28.6
9	21	20	30.9
10	24	12	30.0
11	26	12	34.6
12	28	12	38.9

However, at HRT 12 hours, the TSS removal increased to 38.9% at the end of the week, averaging 34.5%. There are two probable reasons that can explain high removal rate of TSS at two different HRTs. At HRT 36 hours, lower up-flow velocity probably causes self-aggregation of sludges by the microorganisms which enable them to gather suspended solids in leachate to form a structure in sludge blanket. This is due to more contacting time available for them to aggregate and form granular sludges. At HRT 12 hours, higher up-flow velocity probably causes washouts of any suspended materials out of the reactor. Tay et al., (2006) also mentioned that a short HRT in association with a high up-flow velocity can lead to washout of flocculant biological solids and thus it promotes sludge granulation. HRT 20 hours seems to produced worst performance of TSS removal probably due to insufficient up-flow velocity to remove solids and also inadequate contacting time with the sludge.

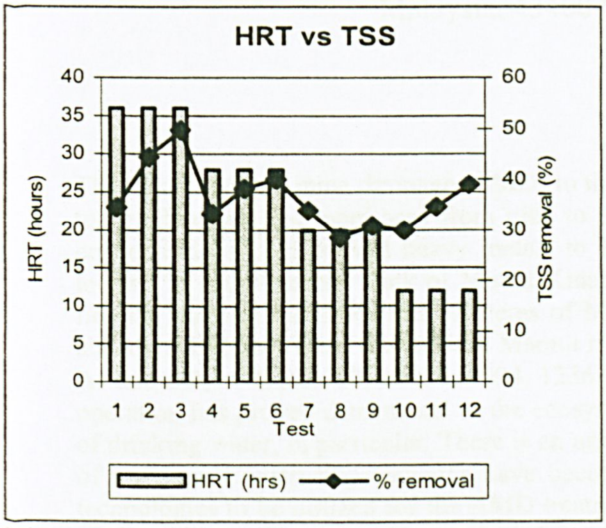

Figure 3: The effect of HRT on TSS removal

CONCLUSIONS

From the experiments, the ideal HRT for the UASB reactor to treat leachate is 36 hours. It seems that longer HRT will give better removal of COD and TSS. This is probably due to longer contacting time of sludge granules with the substrate (leachate). However, there was also substantial removal of TSS at low HRT (high up-flow velocity). Therefore, longer period of HRT is needed to really determine the most appropriate HRT to remove both COD and TSS from landfill leachate efficiently.

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