### ANAEROBIC DIGESTION OF MUNICIPAL SOLID WASTE IN THERMOPHILIC CONTINUOUS OPERATION

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### Abstract:

Anaerobic digestion of Organic Fraction of Municipal Solid Waste (OFMSW) is investigated in continuous operation. During the reactor's start-up period (first phase), the process is stable and there is no inhibition occurred as methane composition increased and leveled off at 66% with higher rate of biogas production. In the second phase, the reactor was fed in continuous mode and the effect of mass retention time (MRT) on the digestion process was investigated. The highest VS degradation of 51%, with biogas production rate of 401 L/kg VS<sub>removed</sub> was achieved with a retention time of 25 days. However, the methane content of the biogas produced was in the range of 30-40%. The drop of methane concentration was traced from the technical problems on reactor configuration and not on the process. Thus, designing a single stage reactor in dry-continuous anaerobic digestion system is a challenge for further investigation.

*Keywords:* Anaerobic digestion, Mass Retention Time, Organic Fraction of Municipal Solid Waste, Thermophilic

### **1. INTRODUCTION**

Solid waste management is an important environmental issue in urban areas. Increased waste generation, rising proportions of packaging and toxic compounds in Municipal Solid Waste (MSW) lead to various problems in waste disposal. Increased environmental awareness and concerns over direct landfilling have stimulated new approaches for solid waste treatment before disposal. Various alternatives are available for pretreatment of Organic Fraction of Municipal Solid Wastes (OFMSW) before disposal namely, biological, physical and chemical processes.

Biological processes like composting and Anaerobic Digestion (AD) provide advantages due to its natural treatment process over other technologies. AD has unique and integrative potential, simultaneously acting as a waste treatment and resource recovery process. AD also showed an excellent Life Cycle Analysis (LCA) performance as compared to other treatment technologies like composting or incineration as it can improve the energy balance (Mata-Avarez, 2003). In addition, the residues are stable compost potential for agricultural purpose (Torres-Castillo et al., 1995).

This research aims at assessing the effectiveness of the AD method as the pretreatment technology of OFMSW prior to landfill using different detention times in a pilot scale reactor in a continuous mode of operation.

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### 2. MATERIAL AND METHODS

#### **2.1 Feedstock Preparation**

Solid waste used in this study was collected from Taklong municipality dumpsite, Pathumthani, Thailand. The representative waste sample was manually segregated to retain the organic fraction and was subjected to particle size reduction (10 mm) by mechanical shredding. During the start-up phase of the process, 20% of total waste loaded during the start-up was added as inoculums. The inoculum consisted of cow dung, anaerobic sludge, digested waste and matured leachate obtained from previous study (Adhikari, 2006). The experiments were carried out in thermophilic (55°C) condition. The chemicals and physical analyses of samples were carried out for every collection in triplicate. Characteristic of the solid waste is presented in Table 1.

Parameters	Value	Parameters (mg/kg TS)	Value			
Moisture content (MC) (%WW)	88-91	Cadmium (Cd)	0.3			
Total solid (TS) (%WW)	9-12	Lead (Pb)	Not Detectable			
Volatile solid (VS) (%TS)	82.3-83.7	Zinc (Zn)	72.2			
Fixed solid (FS) (%TS)	17.7-16.3	Copper (Cu)	15.3			
N (% DM)	3.0	Chromium (Cr)	7.3			
P (% DM)	0.2	Nickel (Ni)	4.1			
K (% DM)	0.2	Manganese (Mn)	88.1			
C (%)	45.7	Mercury (Hg)	0.04			
C/N	15.0					

#### Table1. Feedstock Characteristics

### 2.2 Experimental Set-up

The experiments were performed in a stainless steel horizontal reactor with working volume of 600 L. The reactor's feeding system consists of cover plate attached with a movable shaft and a 2 m piston annexed to the upper left of reactor. At the other side (lower right) an outlet for the digested waste and the leachate is provided that is fitted with movable paddle. Optimum thermophilic condition  $(55^{\circ}C)$  was maintained by a digital temperature controller wherein hot water from water bath is circulating through the double walled jacket of the reactor. The gas outlet of the reactor was connected a gas meter. Additionally, the reactor is well insulated to minimize the heat loss. Figure 1 shows the experimental set-up.

### **2.3 Analytical Methods**

The parameters analyzed for the characterization of OFMSW include Moisture Content (MC), Total Solid (TS), and Volatile Solid (VS) and selected heavy metals such as Cadmium (Cd), Lead (Pb), Zinc (Zn), Copper (Cu), Chromium (Cr), Nickel (Ni), Manganese (Mn), and Mercury (Hg). Nutrients analysis was also conducted by following ASTM standards (1993). Leachate was analyzed daily for the following parameters, pH, alkalinity, VFA, NH<sub>3</sub>-N, TKN using Standard Method for Examination of Water and Wastewater (APHA, AWWA, and WEF, 1998).



### Figure 1. Experimental set-up

& Rotation Paddle

### 3. RESULTS AND DISCUSSION

This research was conducted into two stages, namely: reactor start-up (Phase 1); and continuous operation (Phase 2).

### 3.1 Phase 1: Reactor Start-up

In this phase, the reactor was fed with 300 kg of substrates, which is equal to 80% of reactor's volume. The substrate was mixed well with inoculums (20% of total feedstock) before loading to the reactor to initiate the digestion process. Separate inoculum acclimatization was not conducted. However, the reactor's temperature was started-up in mesophilic and then the temperature was gradually increased by 2°C/day until the optimum thermophilic (55°C) was reached (Adhikari, 2006). This is used as a strategy to avoid the temperature shock load to microorganisms. Moreover, mixing mechanism was provided through leachate percolation with the rate 500 mL/min for three hours daily to enhance biodegradability of the substrates.

### 3.1.1 Biogas Generation and Methane Efficiency

Biogas production and methane concentration in the biogas are primary indicators to evaluate the performance efficiency of the reactor. During the first 8 days of operation, biogas production fluctuated, and from day 9 to 19, it increased sharply. Likewise, methane composition in biogas was increased from day 1 and reached the maximum value of 66% at day 19 (Figure 2). The highest volume of biogas production (520 L/day) was achieved at the same day. It is clearly seen that the volume of biogas increased with the operation time indicating the balanced reactor performance.



Figure 2. Daily cumulative biogas production and methane composition



Figure 3. Profile of pH and VFA

#### 3.1.2 Leachate Characteristics

The pH value of 7 and the concentration of methane (50%) were taken as indicator of active methane phase. However, during the first 2 weeks of operation, pH value was below 7. Thus, pH of the system was adjusted to 7 using commercial grade NaOH. From day 10, the pH and alkalinity value relatively stabilized showing good performance of the reactor.

Figure 3 shows the variation profile of pH and Volatile Fatty Acid (VFA) concentration. The highest concentration of VFA was found on day 3 with the lowest pH of 5.8. It can be concluded that there was a high acidification during the first 3 days and the system lacked sufficient buffering as indicated by lower alkalinity of the system. Methanogenesis is favored between pH 6.8 and 7.2 (Chen et al. 1996). Thus, pH adjustment aided the system in starting up the process of methanogenesis. After that, the pH stabilized in the range of 7-7.8. Interestingly, VFA concentration which reached optimum at the first few days gradually dropped, and thereafter remained constant at 1,000 mg/L, this indicating a balanced condition.

#### **3.2 Phase 2: Continuous operation**

In this phase, continuous feeding was applied in draw-feed mode. Experiments were conducted in two different Mass Retention Times (MRTs) of 25 and 20 days with the loading rate of 2 and 2.5 kgVS/m<sup>3</sup>.day. Mass retention time is defined as the active reactor mass (kg VS) divided by the total wet mass fed each day (kg VS) (Kayhanian and Rich, 1995).

#### 3.2.1 Leachate Characteristic

The pH and alkalinity are the two indicators used to evaluate the performance of the reactor or process stability quickly. The pH and alkalinity significantly decreased from day 54 to 71 (Figure 4). Therefore, the reactor was kept unfed and observed until a balanced condition was reached as indicated by the pH and alkalinity of the system. During the unfed period, the pH and alkalinity gradually increased. The maximum value of pH 7.8 was achieved at day 82. The buffering capacity of the system was recovered during the unfed status due to the gradual increased of alkalinity value up to 10,000 mg/L as CaCO<sub>3</sub>.



Figure 4. pH and alkalinity (Phase 2)

Figure 5 illustrates the daily variation of Dissolved Organic Carbon (DOC) and VFA during different loading rates. These two parameters are the indicators of the hydrolysis rate of anaerobic process. In the continuous loading operation, it was anticipated to get high DOC in leachate which represents the hydrolyzed products from the fresh waste. At the same time, VFA, product of acidification/hydrolysis, influenced the anaerobic digestion process. During the first 20 days of loading 1, DOC remained quite stable with slight fluctuation in the range of 5000-7000 mg/L. VFA also showed the same trends. Thus, VFA was not significantly accumulated to cause any unstable condition as its value was found in the range of 1,000-3,000 mg/L. This value was found in agreement with Veeken et al (2000). Similarly, it was also confirmed that the complete inhibition of anaerobic digestion was at VFA around 4,000-5,000 mg/L. However, when the feeding and withdrawing operation was continued at same rate from day 62 to day 71, both parameters showed increasing trends because the VFA produced was not utilized by methanogenesis, which lead to VFA accumulation. VFA accumulation in the system was indicated by increased carbon dioxide content in biogas due to prevalence of the acidifying microorganisms over the methanogenic ones (Mata-Alvarez, 2003). Immediate precautionary action was taken and reactor was unfed which caused decreasing trends of VFA and DOC. However, when feeding was resumed at day 83 with the loading rate of 2.5 kg  $VS/m^3$ .day, VFA and DOC again increased.



Figure 5. Variation of DOC and VFA (Phase 2)

#### 3.2.2 Biogas Production and Composition

The experiment results showed the fluctuation of daily biogas generated during both feeding rates as graphically presented in Figure 6. In the unfed condition, the average production of 170 L/day was observed from day 72 to day 82. However, cumulative biogas generation was steady. Methane concentration in biogas for both loadings, except at first 3 days of loading and unfed condition was below 50% (Figure 7). It was found that there was a chance of air intrusion during feeding and withdrawal of waste due to some technical problem in the reactor configuration. As oxygen is toxic to the methanogens, lower methane content in the biogas is attributed to the technical problem, not the process.



→ Daily biogas production → Cumulative biogas production

Figure 6. Biogas production (Phase 2)



Figure 7. Biogas composition (Phase 2)

#### **3.3 Overall Process Assessment**

The effect of specific biogas and methane production, VS reduction were taken into account to assess the reactor performance and efficiency of each loading rate. Specific biogas productions for the 2 loading rates are graphically illustrated in Figure 8. The highest specific biogas production on loading rate 1 was 401 L/kgVS <sub>removed</sub>. The specific methane yields obtained were 140.35 and 62.55 L CH<sub>4</sub>/kg VS for loading rate 1 and 2, respectively. This value corresponds to 47.57% and 21.20% process efficiency calculated based on the laboratory BMP assay (295 L CH<sub>4</sub>/kg VS at STP), respectively.

VS degradation of 51% was achieved when operating under loading 1 (2.5 kg VS/m<sup>3</sup>.day). When loading rate was increased, only 43.2% VS reductions were obtained as illustrated in Figure 9. Comparably, VS reduction was lower than the results obtained by Castillo et al. (2006) who reported VS reduction of 77.1% and 74.1% with the digestion time of 25 and 21 days respectively. By far different results in this study were due to the problem mentioned earlier in this section However, the result obtained in terms of VS removal efficiency still in line with Castillo et al. (2006).



#### 4. CONCLUSIONS

This study reveals that a direct and effective start-up of thermophilic anaerobic digestion can be done successfully without inoculum acclimatization. During the continuous operation, when the loading rate was increased, the biogas production decreased. Biogas production rate dropped from 140 L/kgVS to 62.55 CH<sub>4</sub> L/kgVS when loading was increased from 2 kgVS/  $m^3$ .day to 2.5 kg VS/  $m^3$ .day. Volatile solid degradation of 51% was obtained during loading 1 compared to 43.2% in loading 2. Thus, designing a simple single stage reactor in dry-continuous anaerobic digestion system is a challenge for further investigation.

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## Anaerobic Digestion of Municipal Solid Waste in Thermophilic Continuous Operation

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# Introduction



## Landfill & associate problems

- Indispensable component of integrated solid waste management
- Cheap, simple but unsustainable in long term
- Environmental concerns; air, surface /ground water problems
- Mass/volume reduction of MSW better utilization of space
- Asian MSW, high organic fraction (>50%)
   & high moisture content
- Aerobic and anaerobic biological processes: two viable bio-technologies







## Introduction



### Aerobic Versus Anaerobic



### **Anaerobic Digestion Modes**

Low Solids (<10% TS) or High Solids Batch or Continuous Process Mesophilic or Thermophilic

## Problem with batch process

- Safety measures during opening & unloading
- Biogas production variable & somewhat unsteady
- Large land area required
- clogging

## Objectives

- Develop operational design criteria for the horizontal anaerobic reactor under continuous operation using OFMSW as substrate
- Evaluate the performance/efficiency of a continuous reactor with different retention time in continuous mode of operation











## **Pilot Scale Experiments**

### Phase 2: Continuous feeding

(kgVS/m³.d)	Phase 1: Reactor Start- up	Loading 1	Unfed	Loading 2		
	Feeding to reach 80% of reactor volume	Retention time 25 days		Retention time 20 days		
	Leachate     percolation					
	Temperature			Loading rat	e	
	pH Adjustment	Loading rate 2 kgVS/m <sup>3</sup> .d		2.5 kgVS/m <sup>3</sup> .d		-
	1	2		3		4
		Time (mo	onths)			

Loading rate



**Digester** 



## **Experimental Set up**













## **Feedstock Preparation**







### **Feedstock Characteristics**

Parameters	Value			
MC (%ww)	88-91			
TS (%WW)	9-12			
<b>VS (%TS)</b>	82.3-83.6			
N (% D.M)	3.04			
P (% D.M)	0.22			
K (% D.M)	0.22			
C (%WW)	45.73			
C/N	15.04			



Heavy metals	Conc. (mg/ kg D.M)
Cadmium (Cd)	0.25
Lead (Pb)	0
Zinc (Zn)	72.24
Copper (Cu)	15.29
Chromium (Cr)	7.36
Nickel (Ni)	4.10
Mercury (Hg)	0.036
Manganese (Mn)	88.10











### Leachate Characteristics: Start-up







## **Biogas Composition: Continuous Operation**







## Leachate Characteristics: Continuous operation







## **VS Removal**







### **Digested Quality**



Heavy metals below the standards	Heavy metals (mg/kg DM)						
	Cd	Cr	Cu	Pb	Ni	Zn	Hg
Dutch standard (Clean compost)	1	50	60	100	20	200	0.3
WHO standards (Proposed)	3	50	80	150	50	300	-
Digestate	0.6	13.8	55	0	12	106	0.04

Nutrient Values (NPK) were also higher than Thai Compost Standard







- Effective starting up the process without inoculum acclimatization
- Loading rate 1 gave a higher biogas production compared to loading rate 2
- Volatile solid degradation of 51% was observed in loading 1 compared to 43.22% in loading 2.
- End products are stable and has a potential to be used as soil conditioner. Calorific value of digested was 11.16 MJ/kg: potential to be used as RDF
- Based on the investigation and observation, the drop in CH<sub>4</sub> concentration could be linked to the technical design problem rather than the process.
- It is concluded that such a simple system operating in the continuous draw-feed mode has a potential to be incorporated in the decentralized organic waste management system. However, special attention should be given to design of inlet and egress. The research is in progress to overcome the problem.







