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# INFLUENCE OF TEMPERATURE FLUCTUATION ON THERMOPHILIC ANAEROBIC DIGESTION OF MUNICIPAL ORGANIC WASTE

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## ABSTRACT

A laboratory-scale experiment was carried out to estimate the influence of temperature fluctuation on thermophilic anaerobic digestion of municipal organic waste (MOW). Heating failure was simulated by decreasing temperature gradually from 55 °C to 20 °C gradually 2 h time need for temperature decrease and recovery. Under conditions of 8.0 g/ (L·d) and 15 d respectively for MOW load and retention time. Following results were found: (1) biogas production almost stopped and VFA (Volatile Fatty Acid) accumulated rapidly when accompanied by pH decrease. (2) With low temperature (20°C) duration of 1, 5, 12 and 24 h, the thermophilic anaerobic digestion system reproduce methane after temperature fluctuation of 3, 11, 56 and 72 h. (3) The bacteria was influenced by the temperature fluctuation where it decayed, hydrolysis, acidification was high as the low temperature interval lasted. (4) The thermophilic microorganisms were highly flexible to temperature fluctuation.

## KEY WORDS

Temperature fluctuation, Low temperature duration, Thermophilic anaerobic digestion, Municipal organic waste.

## الخلاصة

تم تنفيذ تجارب مختبرية لتخمين تاثير تقلب درجة الحرارة على عمليات الهضم اللاهوائي في درجات الحرارة العالية للنفايةِ الصلبةِ العضويةِ البشرية، بكتريا الميثان تاثرت بتقلب درجة الحرارة حيث ان استمرار طول فترة انخفاض درجة الحرارة يؤدي الى تحللها. درجة حرارة الفشل تمت بتقليل درجة الحرارة بشكل تدريجي خلال ٢ سا ة من ٥٥ C° الى ٢٠ C° ، تحت الحمل العضوي ٨.٠ غم / (لتر ·يوم) وزمن مكوث ١٥ يوم على التوالي. النَتائِج التاليةوُجِدتْ : (١)وَقّفَ إنتاجَ الغاز الحيويتقريباً وتجمع سريع ل (VFA ) مصحوببنقصانِ الدالة الحامضية. (٢)بدرجةِ الحرارةالمنخفضةِ (٢٠ C°)لمدّة ١، ٥، ١٢ و٢٤ ساعةأَخذَ ٣، ١١، ٥٦ و٧٢ ساعةلنظامِ هضمِ اللاهوائي بدرجة الحرارة العالية لإعادة إنتاجالميثانِ بعدقلّبِ درجةِ الحرارة. (٣) طول استمرار فترةَدرجةِ

الحرارة المنخفضةِ بكتيريا الميثان أكثر تحلل، تميع، تحميض وبكتريا الميثانثُأثّرت تقلّبِ درجةِ الحرارة. (٤) الكائنات المجهرية الحية المحبة لدرجات الحرارة العاليةكَانت مرنةجداً إلىقلّبِ درجةِ الحرارة.

## INTRODUCTION

The use of anaerobic process to treat municipal organic waste (MOW) has dramatically increased recently. Anaerobic digestion can be carried out under environment Psychrophilic (<25 °C), mesophilic (25~45 °C) and thermophilic (>45 °C) conditions (El-Mashad et al., 2004). Thermophilic digestion has many advantages such as higher metabolic rate and higher consequent specific growth rate compared with mesophilic digestion, although the thermophilic bacteria death rate is higher (Duran and Speece, 1997). Most of pathogens bacteria are destroyed in the thermophilic anaerobic process (such as fecal coliform, samonella and enterococcus in sewage sludge through thermophilic anaerobic digestion (Watanabe et al., 1997). Salmonella and Mycobacterium paratuberculosis were inactivated within 24 h under thermophilic conditions, while weeks or even months were needed under mesophilic conditions (Sahlstrom, 2003). This is an important criterion for the municipal organic waste treatment where the effluent can be used as a soil conditioner or fertilizer. However, thermophilic treatment also has some disadvantages. Such that it is not so stable and produces low quality effluent compared with mesophilic process (Duran and Speece, 1997). Moreover, thermophilic anaerobic digestion is bacterized by more toxicity and susceptible to variations in operational and environmental conditions, such as temperature fluctuation. The above results were obtained from experiments conducted in a complete mixed system which was relatively more sensitive at any temperature range (Peck et al., 1986). The results of Ahring et al. (2001) showed that the operational temperature increasing from 55 °C to 65 °C unbalances the fermenting, acids-producing micro - organisms and acids-consuming micro-organisms. Another disadvantage less net energy was produced from thermophilic digestion compared with the mesophilic digestion. Digestion performance was adversely affected by both gradually temperature increase and decrease (Ahn and Forster, 2002). Along with sudden temperature variation, there were some increase in concentrations of all the (volatile fatty acids VFAs) (acetate and propionate), especially acetic and propionic acid (Dohanyos et al., 1985). The extent of influences depended both on the magnitude of temperature variation and durability of bacterial in activated sludge (El-Mashad et al., 2004). If temperature was beyond the durability of bacteria, their death rate would exceed growth rate and consequently result in a decrease of the reactor removal capacity (Visser et al., 1993). Van Lier et al.(1996). Observed that large-scale thermophilic anaerobic installations, such as UASB (up-flow anaerobic sludge bed) reactors, can tolerate moderate temperature fluctuation due to the substrate transfer limitation by granulation of immobilized sludge. This work aimed at investigating the influence of gradually temperature fluctuation on thermophilic anaerobic digestion of MOW. The parameters such as biogas production, CH4 content, pH, VFA and acetate and propionate were researched in this study.

## METHODS AND MATERIALS

### Experimental setup

Four experiments were carried out simultaneously. Every experiment had two reactors in order to obtain the results expressed as mean values. The operating temperature was decreased from 55 °C to 20°C (approx. room temperature), and was returned to 55°C within 2 h. And low temperature (20°C) durations lasted for 1, 5, 12 and 24 h respectively. The experiment parameters measured were biogas production, methane content, pH and VFAs. Which were measured every 1~5 h during the experiments duration. The organic load was 8.0 g/(L·d) (as volatile solid) and duration time of 15 d were chosen for each test. The gas production was monitored with water displacement in a gas collector. The water in the gas collector was acidified with thin sulfuric acid and saturated with NaCl to prevent $CO_2$ from dissolving in the biogas.

## DIGESTER

Eight laboratory-scale glass digesters with volume of 2 L as shown in Fig.1 were used. The flasks were closed with rubber stoppers equipped with glass tubes for gas removal and effluent/influent flow. The reactor temperature was regulated by controlling water temperature in a water bath where the reactor was placed and maintained within ±1°C in a steady state, assuming to have stable biogas yield, pH, VFA and reactor temperature. The digesters were stirred by hand for 5 min before and after feeding with organic sludge otherwise the digesters were unstirred.

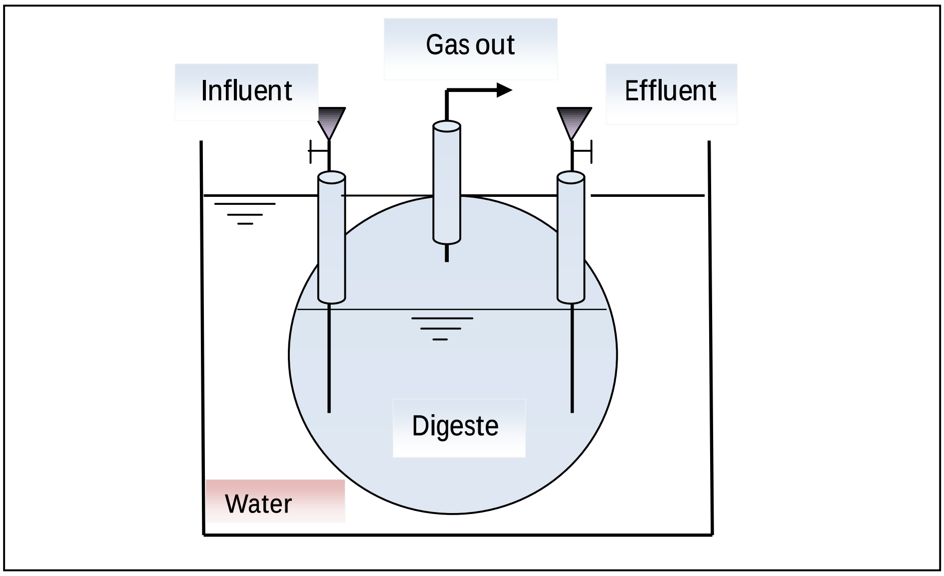



**Fig.1 Schematic diagram of the reactor used**

## FEEDSTOCK

The digesters were fed daily with hand sorted municipal organic waste (like leaving foods) (MOW), and inoculated with sludge from septic-tank. The waste was transported to laboratory and mixed. The total solid (TS) and volatile solid (VS) were 15.5% and 88.6% respectively, and pH values were 7.1~7.3.

**Table 1: Characteristics of MOW after pretreatment of digester feed material**

| Component | Food waste | Paper | Inorganic | Others | Total |
|---|---|---|---|---|---|
| Content (wt%) | 86.2 | 7.5 | 3.9 | 2.4 | 100 |

## ANALYSIS

TS and VS concentrations were measured by the standard gravimetric techniques (Li, 2004). Biogas in the gas collector was measured. The composition of biogas was measured by 1904 gas analysis instrument. $N_2$ was used as the carrier gas at a flow rate of 90 ml/min. The total VFA was measured by the titration method (Lau, 1997). The composition of the VFA was analyzed by a gas chromatography equipped with a flame ionization detector (FID) and a glass column, also $N_2$ was carrier gas but at a flow rate of 40 ml/min.

## RESULTS AND DISCUSSION

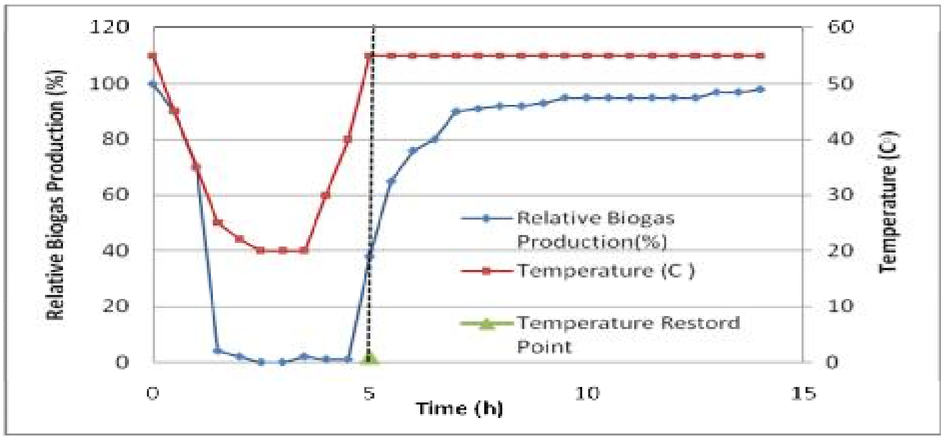
### Biogas production variation

Figs.2a~2d shows the relative biogas production fluctuation at low temperature duration of 1, 5, 12 and 24 h respectively. The relative biogas production was determined from

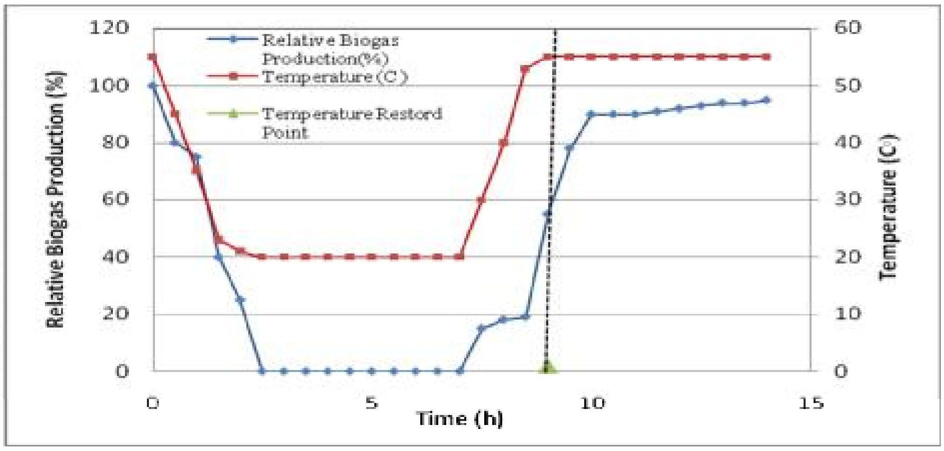
$$Pr = Pt / Po \times 100\ \%$$

Pr: relative biogas production (%).
Pt: biogas yield after the temperature fluctuation (ml/g $VS_{added}$).
$P_0$: biogas yield before the temperature fluctuation (ml/g $VS_{added}$).

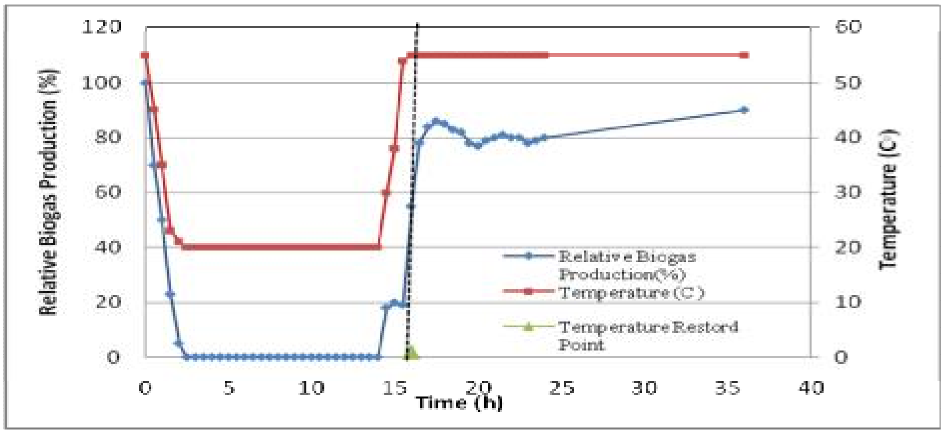
When temperatures decreased rapidly within 2 h from 55°C to 20°C, the relative biogas production stopped (Fig.2). Biogas production was restored after the temperature increased. Biogas production resumption time was longer with longer low temperature duration. The production increased rapidly then decreased when temperature was restored in the low temperature duration of 12 h and 24 h.



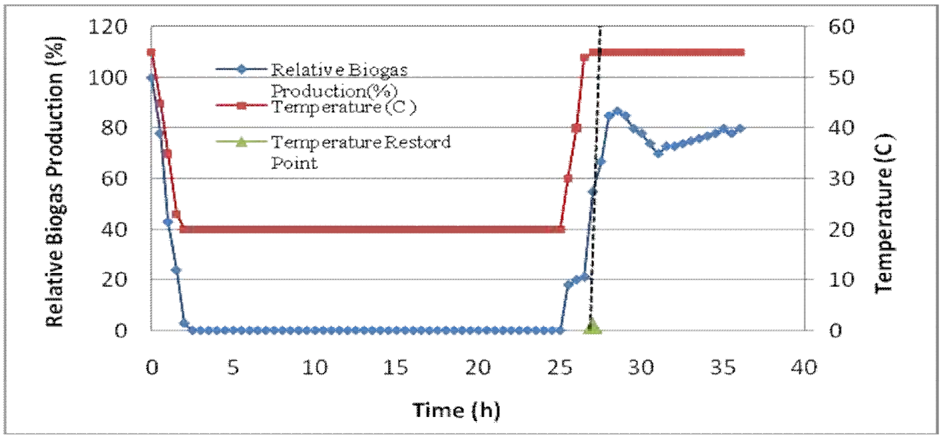

(a)




(b)



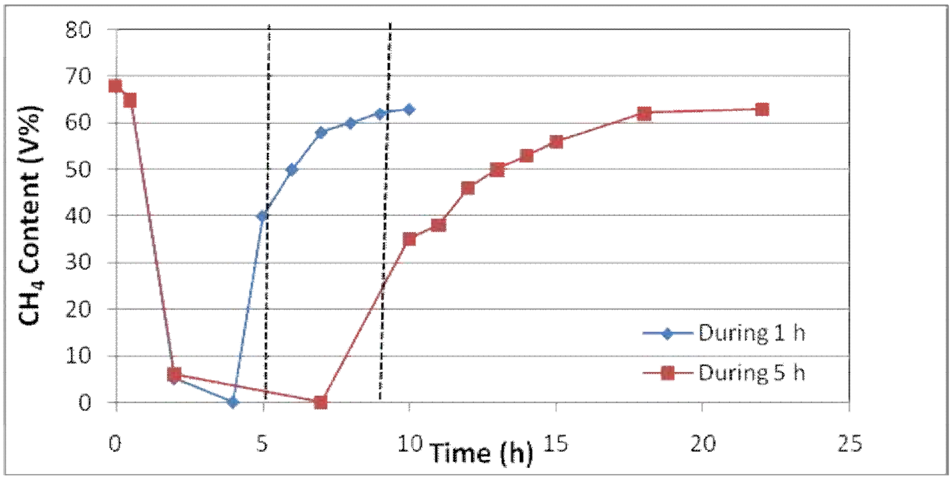

(c)



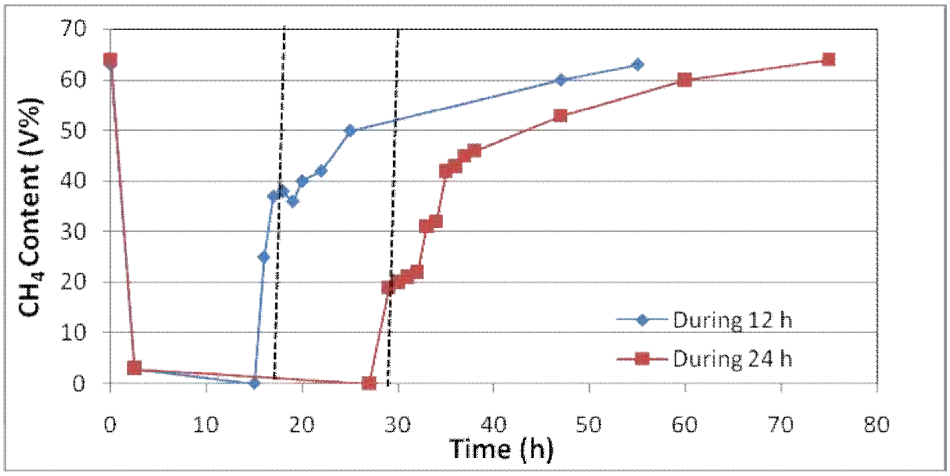

(d)

**Fig.2 The biogas production fluctuation during (a) 1 h, (b) 5 h, (c) 12 h and (d) 24 h**

The main content of biogas at beginning was $CO_2$ instead of $CH_4$; there were two different sources of $CO_2$. One was produced by vaporization of dissolved $CO_2$ at low temperature during temperature increase (Peck et al., 1986). The other was presumably due to the rapid fermentation and hydrolysis as the temperature increased. Vaporization of dissolved $CO_2$ was the main source. After temperature was restored dissolved $CO_2$ decreased where methane production lagged the temperature restoration time (Fig.3). The delay time of methane production was 4, 7, 55 and 75 h respectively at low temperature duration of 1, 5, 12 and 24 h, which showed that longer low temperature duration led to more decay of methanogenic bacteria. The delay in recovery was presumably due to the slow degradation of relatively low methane-yielding cellulosic materials. The cellulytic bacteria had responded considerably more slowly to the rapid temperature rise than some other digester bacteria (Peck et al., 1986). As cellulose is non-toxic, the only effect was a delayed return to steady-state condition.




(a)



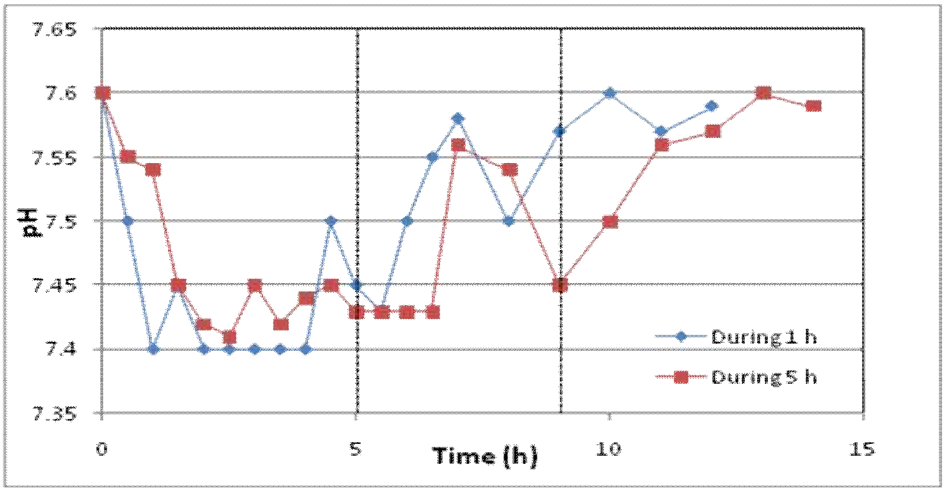

(b)

**Fig.3 Methane content fluctuation (a) during 1 h and 5 h, (b) during 12 h and 24 h**

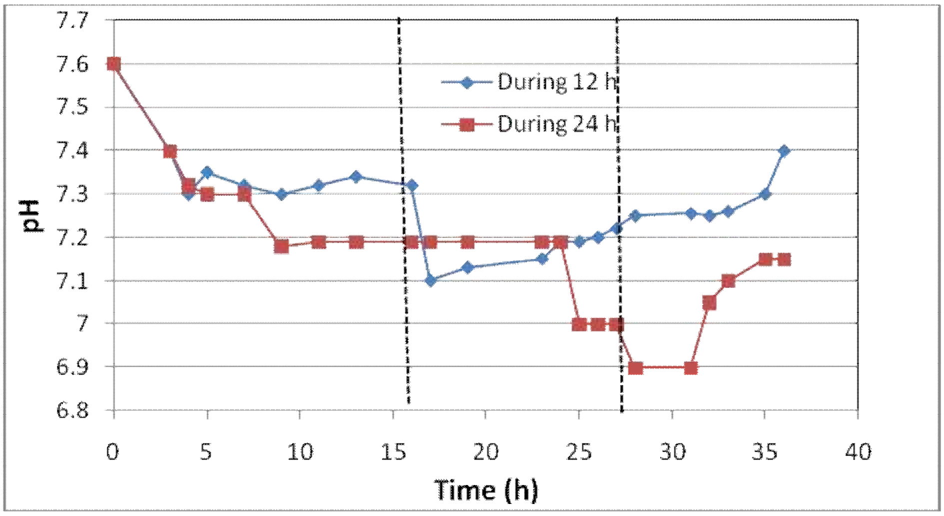
## PH VALUES VARIATION

Fig.4 shows pH values variation during experiments. pH was between 6.9 to 7.6 in all reactors during low temperature period. These results differed from those reported by Lau and Fang (1997), who showed that when UASB reactor was used to treat wastewater with organic load of 10 g COD/(L·d) and temperature decreased from 55°C to 37°C, pH decreased from 6.9~7.3 to 6.3 (Lau and Fang, 1997). pH values decrease could be attributed to the VFA accumulation (Fig.5) and increase of dissolved $CO_2$ at low temperature pH values decreased more in the reactor at long low temperature duration for 1 and 5 hr duration the pH decreased to 7.4 where at 24 hr duration it decreased to 7.0 as shown in fig. 4. When the temperature returned to 55°C and low temperature durations were 12 and 24 h, the pH decreased further due to the further accumulation of VFA. The relatively large resistance against pH variation was presumably due to the buffering effect caused by $CO_2$ vaporization and increasing content of ammonia. The solubility of $CO_2$ at 60°C was approximately half that at 35°C. Protein was degraded faster in thermophilic anaerobic digestion than in mesophilic conditions which resulted in the increase of ammonia (Speece, 2001). The above conditions provided the alkalinity for the digester. The production of alkalinity by degradation of protein was as follows (Speece, 2001):

$$\mathbf{RCHNH_2COOH+2H_2O \rightarrow RCOOH+NH_3+CO_2+2H_2}$$
$$\mathbf{NH_3+H_2O+CO_2 \rightarrow NH_4+HCO_3^-}$$




(a)

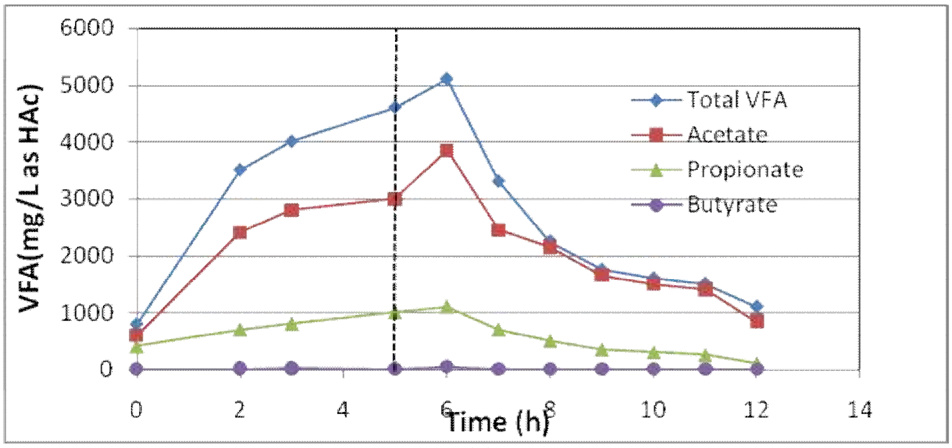



(b)

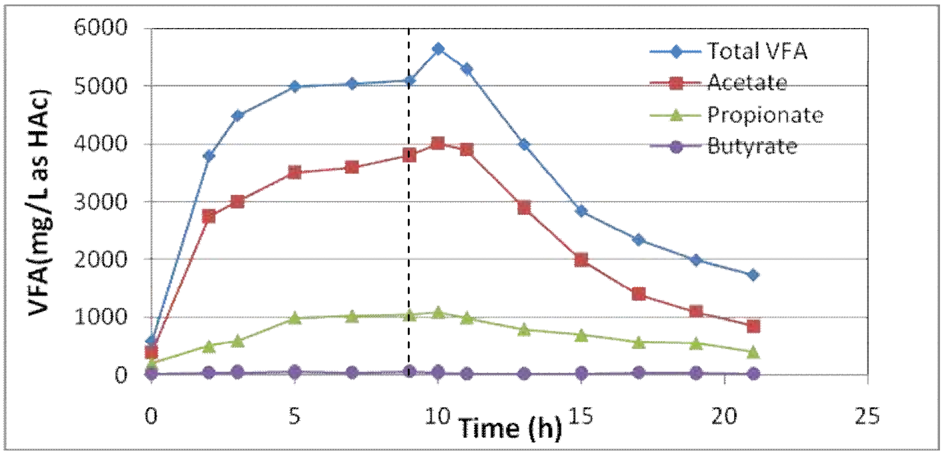
**Fig.4 pH variations in the experiments (a) during 1 h and 5 h; (b) during 12 h and 24 h**

## VFA CHANGES IN THE EXPERIMENTS

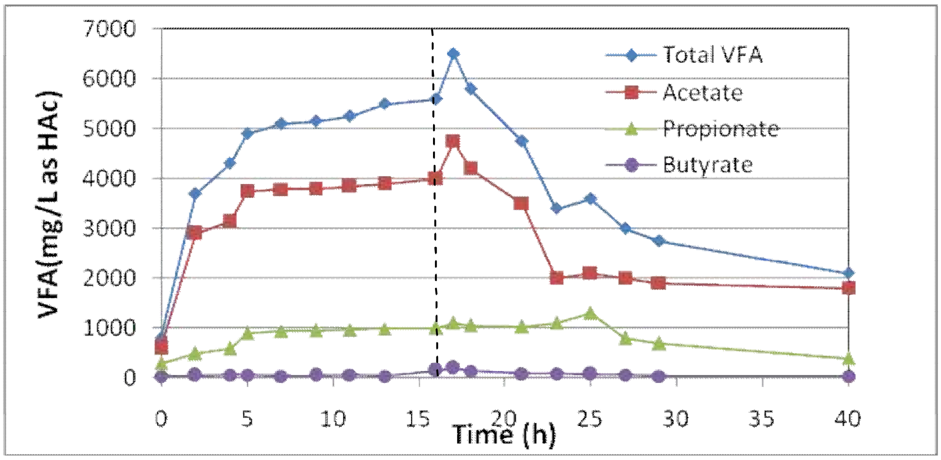
Fig.5 shows that concentrations of total VFA, acetate and propionate increased immediately as the temperature decreased in the thermophilic reactors and led to transient decrease of pH in the digester (Fig.4). For example, when the temperature had decreased to 20 °C for 1 h, concentrations of total VFA, acetic and propionic acid increased from 600, 400 and 140 mg/L to 4200, 3200 and 900 mg/L respectively. When the low temperature duration was 5, 12 and 24 h respectively, VFA concentrations increased more than 1 h (Fig.5), which was partly due to the addition of acids in the feed which were not metabolized due to decrease of metabolic activity at the low temperature for 24 h. However, VFA variation was relative stable in later period 5, 12 and 24 h of low temperature duration. These results were in attributable to temperature fluctuation which decreased the hydrolysis and fermentation activity. Different volatile fatty acids increased to different extent suggests that the microorganisms have not all responded in an identical manner to sudden temperature fluctuation, there was an unbalance of microorganisms in the digester (Lau, 1997). Another reason was that acids were not removed at the same rate. The propionate and butyrate decreased very slowly (Fig.5) because of the limitation of high concentration of acetate and hydrogen partial pressure. Mosey (1982) presented mathematical model to predict the different response of volatile fatty acids to shock treatment. This model proposes that a rise in hydrogen partial pressure will bring about higher rise in the concentration of propionic acid than of acetic or butyric acid. Initial high accumulation of the level of volatile fatty acids with simultaneous lower biogas yield, indicated that fermentation and methanogenic consortia were severely affected by the temperature decrease under different low temperature duration (Fig.5). When the temperature returned to normal level acetate was first acid to be degraded, indicating that acetate degradation was highly influenced by temperature increase. And acetate only accumulated for short period after resumption of operational temperature indicating that the microbial populations present in the reactor could take over the activity of the acetate-utilizing methanogenic archaea (Lau, 1997).


VFA(mg/L as HAc)
6000
5000
4000
3000
2000
1000
0
0
2
4
6
8
10
12
14
Time (h)
Total VFA
Acetate
Propionate
Butyrate

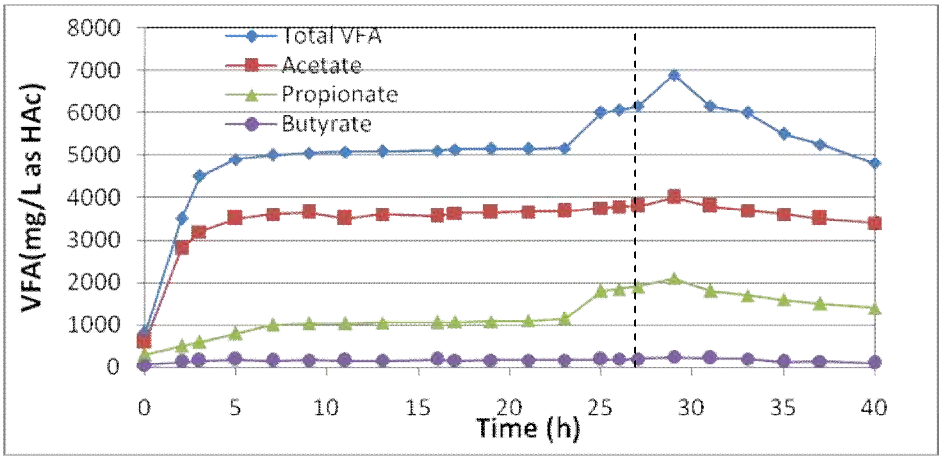
(a)


VFA(mg/L as HAc)
6000
5000
4000
3000
2000
1000
0
0
5
10
15
20
25
Time (h)
Total VFA
Acetate
Propionate
Butyrate

(b)


VFA(mg/L as HAc)
7000
6000
5000
4000
3000
2000
1000
0
0
5
10
15
20
25
30
35
40
Time (h)
Total VFA
Acetate
Propionate
Butyrate

( c)




(d)

**Fig.5 The total VFA and VFAs fluctuation during (a) 1 h, (b) 5 h, (c) 12 h and (d) 24 h**

## CONCLUSIONS

1. The experiment results showed that the biogas production almost stopped and the total VFA, acetate and propionate were rapidly accumulated when temperature fluctuated. The pH values reduced transiently. These parameters would be restored when the temperature returned to normal operation levels though some of them lagged dramatically the recovery time.

2. The delay time of methane production were respectively 3, 11, 56 and 72 h at the different low temperature durations which showed that the longer low temperature duration was the more methane bacteria would decay.

3. With longer duration at low temperature there would be much more delay for thermophilic anaerobic digestion system to return to the steady state condition so the digester temperature should be raised back to normal the operating temperature as soon as possible after a heating failure.

4. Thermophilic microorganisms appeared to be highly resilient temperature fluctuations in the process.

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