Journal of Zhejiang University SCIENCE B
ISSN 1673-1581 (Print); ISSN 1862-1783 (Online)
www.zju.edu.cn/jzus; www.springerlink.com
E-mail: jzus@zju.edu.cn

Influence of temperature fluctuation on thermophilic anaerobic digestion of municipal organic solid waste*

WU Man-chang[†1], SUN Ke-wei[2], ZHANG Yong[1]

([1]*School of Environmental Science and Engineering, Kunming University of Science and Technology, Kunming 650093, China*)

([2]*National Engineering Research Center of Solid Waste Resource Recovery, Kunming 650033, China*)

[†]E-mail: wyuc@sina.com

Received Aug. 8, 2005; revision accepted Nov. 30, 2005

Abstract: A laboratory-scale experiment was carried out to assess the influence of temperature fluctuation on thermophilic anaerobic digestion of municipal organic solid waste (MOSW). Heating failure was simulated by decreasing temperature suddenly from 55 °C to 20 °C suddenly; 2 h time is needed for temperature decrease and recovery. Under the conditions of 8.0 g/(L·d) and 15 d respectively for MOSW load and retention time, following results were noted: (1) biogas production almost stopped and VFA (volatile fatty acid) accumulated rapidly, accompanied by pH decrease; (2) with low temperature (20 °C) duration of 1, 5, 12 and 24 h, it took 3, 11, 56 and 72 h for the thermophilic anaerobic digestion system to reproduce methane after temperature fluctuation; (3) the longer the low temperature interval lasted, the more the methanogenic bacteria would decay; hydrolysis, acidification and methanogenesis were all influenced by temperature fluctuation; (4) the thermophilic microorganisms were highly resilient to temperature fluctuation.

Key words: Temperature fluctuation, Low temperature duration, Thermophilic anaerobic digestion, Municipal organic solid waste
doi:10.1631/jzus.2006.B0180 **Document code:** A **CLC number:** X703.1

INTRODUCTION

The use of anaerobic process to treat municipal organic solid waste (MOSW) has dramatically increased recently. Anaerobic digestion can be carried out under ambient (<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 are destroyed in the thermophilic anaerobic process which is effective against pathogenic bacteria (such as *felcal 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 will be needed under mesophilic conditions (Sahlstrom, 2003). In fact this is an important criterion for the municipal solid waste treatment, since the effluent can be used as a soil conditioner or fertilizer.

However, thermophilic treatment also has some disadvantages. For example, it is not so stable and produces somewhat 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 findings 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

* Project (No. 2002-548) supported by the National Development and Reform Commission of China

°C unbalances the fermenting, acids-producing micro-organisms and acids-consuming micro-organisms. Another disadvantage was that the net energy production from thermophilic digestion was less than that of mesophilic digestion as a result of increased energy requirement achieving high temperature in thermophilic process.

Digestion performance was adversely affected by both sudden temperature increase and decrease (Ahn and Forster, 2002). Along with sudden temperature variation, there were some increases in concentrations of all the volatile fatty acids (VFAs), 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. As there was insufficient information on the influence of sudden temperature fluctuation on thermophilic anaerobic digestion for MOSW, this paper aimed at investigating the influence of sudden temperature fluctuation on thermophilic anaerobic digestion of MOSW. The parameters such as biogas production, CH_4 content, pH, VFA and VFAs 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 duplicate expressed as mean values. The operating temperature was decreased from 55 °C to 20 °C (approx. room temperature of Kunming City), and returned to 55 °C within 2 h. And low temperature (20 °C) durations were 1, 5, 12 and 24 h respectively. The experiment parameters were biogas yield, methane content, pH, VFA. They were measured every 1~5 h during the experiments. It was 8.0 g/(L·d) (as volatile solid) and 15 d respectively for organic load and retention time (RT). The gas production was monitored with a water displacement 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 identical laboratory-scale glass digesters with working volume of 2 L are shown in Fig.1. The vials were closed with butyl rubber stoppers equipped with glass tubes for gas removal and effluent/influent. The reactor temperature was regulated by controlling water temperature in the water bath in which the reactor was placed and maintained within ±1 °C in the steady state, which was assumed to have stable biogas yield, pH, VFA and reactor temperature. The digesters were stirred by hand for 5 min before and after feeding; otherwise the digesters were unstirred.

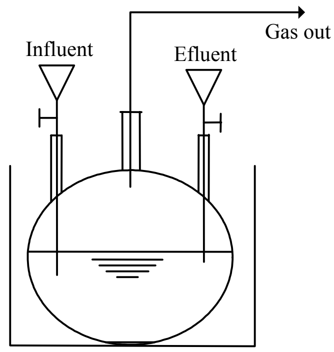

Fig.1 Schematic presentation of the reactor used

Feedstock

The digesters were fed daily with hand sorted municipal organic solid waste (MOSW) from the university settlement in the Kunming University of Science and Technology, and inoculated with sludge from the mankind septic-tank. The waste was transported to laboratory and blended. Its physicochemical characteristics were listed in Table 1. Total solid (TS) and volatile solid (VS) were 15.5% and 88.6% respectively, and pH values were 7.1~7.3.

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 and gas chromatography equipped with a thermal conductivity detector (TCD) and a stainless-steel column. N_2 was used as the carrier gas at flow rate of 90 ml/min. The total VFA was measured by the titration method. The composition of the VFA was analyzed by a gas chromatography equipped with a flame ionization detector (FID) and a glass column. N_2 was carrier gas at flow rate of 40 ml/min.

RESULTS AND DISCUSSION

Biogas production variation

Figs.2a~2d show the relative biogas production fluctuation of low temperature duration of 1, 5, 12 and 24 h respectively. The relative biogas production was determined as follows: the production was considered to 100% before the temperature fluctuation, then the biogas production after the temperature fluctuation was proportion to it, defined as:

$$P_r=P_t/P_0\times100\%,$$

P_r: relative biogas production (%); P_t: biogas yield after the temperature fluctuation (ml/g VS_{added}); P_0: biogas yield before the temperature fluctuation (ml/g VS_{added}).

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

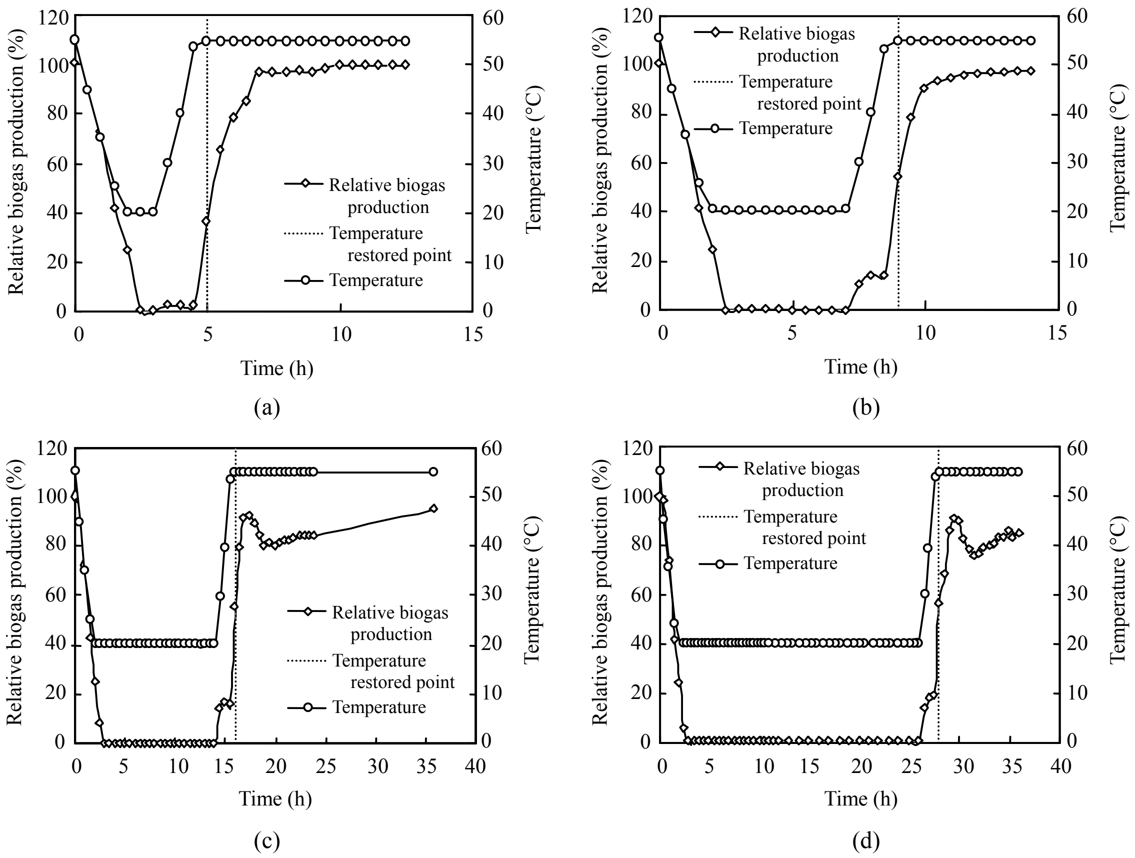

Fig.2 The biogas production fluctuation during (a) 1 h; (b) 5 h; (c) 12 h; (d) 24 h

Table 1 Characteristics of MOSW after pretreatment of digester feed material

Component	Food waste	Paper	Straw	Inorganic	Others	Total
Content (wt%)	86.2	3.5	4.5	3.4	2.4	100

decreased slightly when temperature was restored in the low temperature duration of 12 h and 24 h. The main content of biogas at the 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 the temperature increase (Peck *et al*., 1986). Another was presumably due to the rapid fermentation and hydrolysis as the temperature was increased. Vaporization of dissolved CO_2 was the main source. After temperature was restored, the dissolved CO_2 decreased, but the methane production lagged the temperature restoration time (Fig.3). The delay time of methane production was 3, 11, 56 and 72 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.

pH values variation

Fig.4 shows pH values variation during the experiments. Generally, pH was 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). The pH values decrease could be attributed to the VFA accumulation (Fig.5) and increase of dissolved CO_2 at low temperature. The longer the low temperature duration was, the more pH would decrease in the reactor. 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

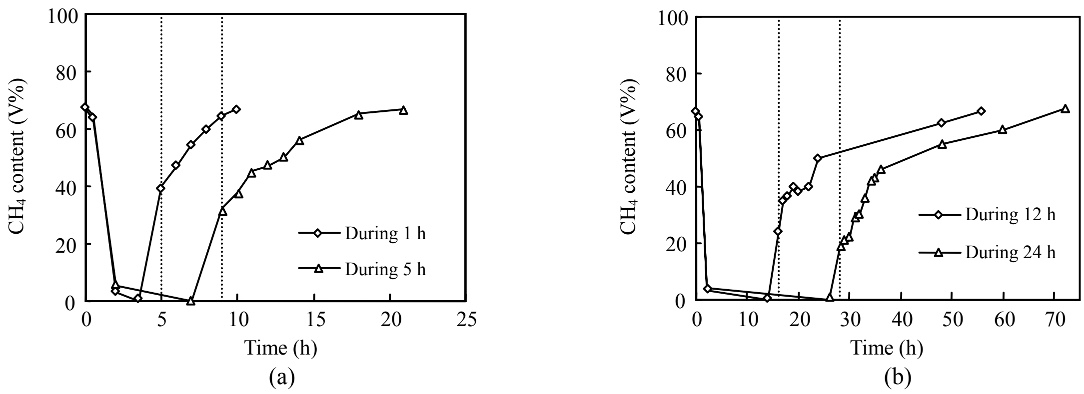

Fig.3 Methane content fluctuation (a) during 1 h and 5 h; (b) during 12 h and 24 h

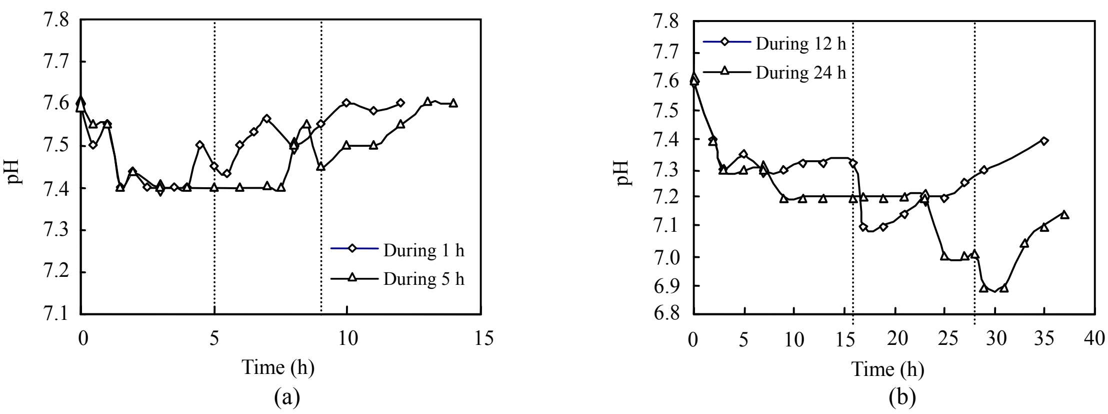

Fig.4 pH variations in the experiments (a) during 1 h and 5 h; (b) during 12 h and 24 h

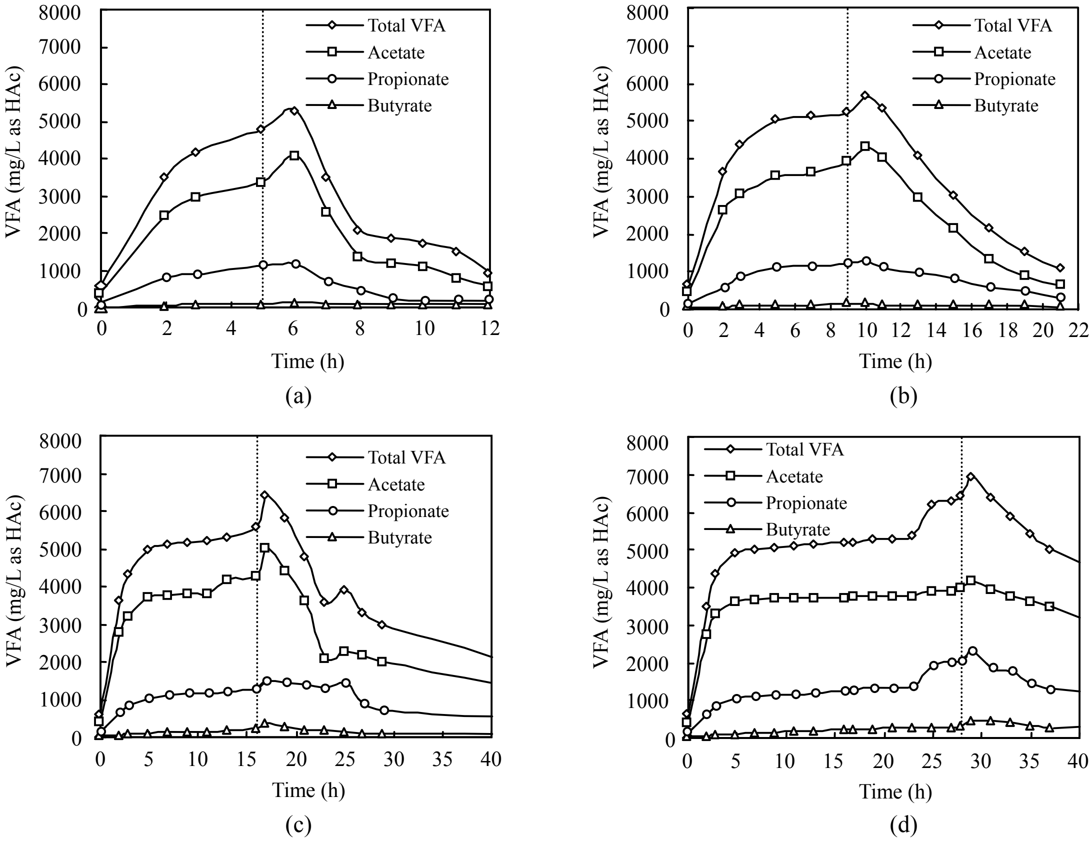

Fig.5 The total VFA and VFAs fluctuation during (a) 1 h; (b) 5 h; (c) 12 h; (d) 24 h

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):

$$RCHNH_2COOH+2H_2O \rightarrow RCOOH+NH_3+CO_2+2H_2$$

$$NH_3+H_2O+CO_2 \rightarrow NH_4^+ + HCO_3^-$$

VFA changes in the experiments

Fig.5 shows that concentrations of total VFA, acetate and propionate increased immediately as a result of sudden temperature decrease in the thermophilic reactors and led to a 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 for more than 1 h (Fig.5), which was also 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 the later period 5, 12 and 24 h of low temperature duration. These results were presumably attributable to the temperature fluctuation which decreased the hydrolysis and fermentation activity. The fact that different volatile fatty acids increased to a different extent suggests that the microorganisms have not all responded in an identical manner to the sudden temperature fluctuation, and that there was an unbalance of microorganisms in the digester. 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 a mathematical model to predict the different response of volatile fatty acids to shock treatment. This model proposes that a rise in the hydrogen partial pressure will bring about a higher rise in the concentration of propionic acid than that 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 the first acid to be degraded, indicating that acetate degradation was highly influenced by temperature increase. And acetate only accumulated for a short period after resumption of operational temperature, indicating that the microbial populations already present in the reactor could take over the activity of the acetate-utilizing methanogenic archaea.

CONCLUSIONS

1. The experiment results showed that the biogas production almost stopped and that the total VFA, VFAs such as acetate and propionate were rapidly accumulated when the temperature fluctuated. The pH values were also reduced transiently. All of them would be restored when temperature returned to normal operational level 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 the low temperature duration was, the more methanogenic the bacteria would decay.

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

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

References

Ahn, J.H., Forster, C.F., 2002. The effect of temperature variations on the performance of mesophilic and thermophilic anaerobic filters treating a simulated papermill wastewater. *Process Biochemistry*, **37**(6):589-594. [doi:10.1016/S0032-9592(01)00245-X]

Ahring, B.K., Ibrahim, A.A., Mladenovska, Z., 2001. Effect of temperature increase from 55 °C to 65 °C on performance and microbial population dynamics of an anaerobic reactor treating cattle manure. *Water Res.*, **35**(10): 2446-2452. [doi:10.1016/S0043-1354(00)00526-1]

Dohanyos, M., Kosova, B., Zabranska, J., 1985. Production and utilization of VFA's in various types of anaerobic reactors. *Water Sci. Technol.*, **17**:191-205.

Duran, M., Speece, R.E., 1997. Temperature staged anaerobic processes. *Environmental Technology*, **18**:747-754.

El-Mashad, H.M., Zeeman, G., van Loon, W.K.P., Gerard, P.A.B., Lettinga, G., 2004. Effect of temperature and temperature fluctuation on thermophilic anaerobic digestion of cattle manure. *Bioresource Technology*, **95**(2):191-201. [doi:10.1016/j.biortech.2003.07.013]

Lau, I.W.C., Fang, H.P., 1997. Effect of temperature shock to thermophilic granules. *Water Res.*, **31**(10):2626-2632. [doi:10.1016/S0043-1354(97)00110-3]

Li, G.D., 2004. The Handbook of Environment Engineering for Treating Solid Waste. Higher Education Press, Beijing, p.64-94.

Mosey, F.E., 1982. Mathematical modelling of the anaerobic digestion: regulated mechanisms for the formation of short-chain volatile acids from glucose. *Water Sci. Technol.*, **15**:209-232.

Peck, M.W., Skilton, J.M., Hawkes, F.R., Hawkes, D.L., 1986. Effects of temperature shock treatments on the stability of anaerobic digesters operated on separated cattle slurry. *Water Res.*, **20**(4):453-462. [doi:10.1016/0043-1354(86)90193-4]

Sahlstrom, L., 2003. A review of survival of pathogenic bacteria in organic waste used in biogas plants. *Bioresource Technology*, **87**(2):161-166. [doi:10.1016/S0960-8524(02)00168-2]

Speece, R.E., 2001. Anaerobic Biotechnology for Industrial Wastewaters. Architecture & Building Press, Beijing, p.198~202.

van Lier, J.B., Martin, J.L.S., Lettinga, G., 1996. Effect of temperature on the anaerobic thermophilic conversion of volatile fatty acids by dispersed and granular sludge. *Water Res.*, **30**(1):199-207. [doi:10.1016/0043-1354(95)00107-V]

Visser, A., Gao, Y., Lettinga, G., 1993. Effects of short-term temperature increases on the mesophilic anaerobic breakdown of sulfate containing synthetic wastewater. *Water Res.*, **27**(4):541-550. [doi:10.1016/0043-1354(93)90163-C]

Watanabe, H., Kitamura, T., Ochi, S., Ozaki, M., 1997. Inactivation of pathogenic bacteria under mesophilic and thermophilic condition. *Water Sci. Technol.*, **36**(6-7): 25-32. [doi:10.1016/S0273-1223(97)00503-9]