ISSN 1001—0742
Journal of Environmental Sciences Vol. 18, No. 4 pp. 810—815, 2006 CN 11—2629/X

Article ID: 1001-0742(2006)04-0810-06 **CLC number**: X705 **Document code**: A

Influence of temperature on performance of anaerobic digestion of municipal solid waste

ZHANG Ji-shi[1,2,*], SUN Ke-wei[1], WU Man-chang[2], ZHANG Lei[1]

(1. National Engineering Research Center of Solid Waste Resource Recovery, Kunming 650033, China. E-mail: lyzhanghua@sohu.com; 2. Faculty of Environmental Science and Engineering, Kunming University of Science and Technology, Kunming 650093, China)

Abstract: The influence of temperature on the performance of anaerobic reactors for treating the organic fraction of municipal solid waste (OFMSW) was studied. Batch digestion of OFMSW was carried out for 32 d at different temperature (25℃, 35℃, 45℃ and 55℃) conditions for total solid concentrations (TS) 17% with the ratio of total organic carbon to nitrogen (C/N) being, 25:1 respectively, while keeping other parameters constant such as inoculum, start-up pH, reactor volume (2 L) and so on. Temperature can influence the methanogenic bacteria activity, accordingly inhibiting the OFMSW biodegradation and stabilization efficiency. Anaerobic reactors excelled at TS reduction, total volatile solid reduction, chemical oxygen demand reduction, increasing cumulative biogas production, whose rate was at temperature (35℃ and 55℃) conditions. Methane concentration in the biogas was above 65% in four reactors. In addition, the fluctuation of temperatures resulted in the biogas production variation. The data obtained indicated that temperature had a significant influence on anaerobic process.

Keywords: municipal solid waste; anaerobic digestion; batch processing; temperature

Introduction

From an environmental viewpoint, there is an urgent need for appropriate management of municipal solid waste (MSW). Nearly 1600×10^6 t/a of MSW are generated worldwide with up to 43% contributed by Asia and Oceania and 28% contributed by North America and the European Union (Bertolini, 2000). Sustainable waste treatment concepts that favor waste recycling and the recirculation of nutrients back to soil will have the highest benefit for the environment (Lema and Omil, 2001; Sakai *et al.*, 1996; Braber, 1995). Sanitary landfills represent a common, economical and environmentally acceptable method for the disposal of solid waste. Even with implementation of waste reduction, recycling and transformation technologies, the disposal of residual solid waste in landfills still remains an unavoidable component of an integrated solid waste management strategy (Chugh *et al.*, 1999).

However, MSW contains an easily biodegradable organic fraction (OF) of up to 40%—50% (Sosnowski *et al.*, 2003; Yu *et al.*, 2002), which can result in contaminating air, soil and water by land filling. There are various methods used for stabilization of organic waste, including composting and anaerobic digestion. The composting causes quick decomposition but also results in uncontrolled release of carbon dioxide to the atmosphere which brings about greenhouse effect without the potential benefit of capturing energy of the waste. In contrast, the anaerobic digestion appears to be a promising alternative for the treatment of organic solid waste due to reducing the volume of the waste, creating a stable by-product in the form of a humus, and producing biogas with 40% —60% methane, which can be achieved (Kayhanian, 1995). Biological treatment of organic fraction of wastes of municipal solid wastes (OFMSW) is competing with incineration as the only alternative treatment since landfilling is banned in Denmark (Hinrich *et al.*, 2004). However, the application of the anaerobic digestion for the organic solid waste treatment is still not widely spread into practice due to the lack of appropriate treatment system configurations and, mainly due to the longer time required for the biostabilization. Decreasing the biostabilization time of organic solid waste with the utilization of inoculum had shown satisfactory results (Lopes *et al.*, 2004).

Anaerobic digestion process can be developed over different temperature ranges including: mesophilic temperature of around 35℃ and thermophilic temperatures in the range 55—60℃. Methanogenic activity were reported by psychrophilic anaerobic bacteria at temperatures below 15℃ (Kettunen and Rintala, 1997; Vavilin *et al.*, 1998, 2000) and by extremophiles at temperatures above 65℃. Conventional anaerobic digesters operate at mesophilic or thermophilic temperatures, or in the case of tropical countries at ambient temperatures. In tropical countries the control of temperature is not a common practice and the digestion process will depend on the changes of temperatures between the day and night and the weather conditions. The changes of temperature in these countries can be in the range of 5—10℃ round the clock.

Temperature plays a vital role in degrading organic fracture of municipal solid waste by anaerobic process (Sung and Santha, 2003), which can significantly affect the conversion, kinetics, stability, effluent quality and consequently the methane yield.

Foundation item: The Foundation of Committee for National Development and Innovation(No. 2002548); *Corresponding author

ZENG *et al.* (2003) studied that temperature affected most remarkable followed by total solid (TS); the C:N ratio influence coefficient was the least in the complete mix anaerobic digestion of municipal solid waste. It was indicated that the anaerobic degradation rate of organic matter increase with temperature when psychrophilic, mesophilic and thermophilic processes are compared. Gallert *et al.* (Gallert and Winter, 1997; Gallert *et al.*, 1998) reported that inhibition due to ammonia accumulation affected the mesophilic process more than the thermophilic one. Mackie and Bryant (1995) studied the anaerobic digestion of cattle wastes at mesophilic and thermophilic temperatures and found that methane yield was more affected in mesophilic digestion when the organic load was increased and retention time reduced in a completely mixed digester on a laboratory scale. Sa′nchez *et al.* (2002) demonstrated an increase of the methane yield when mesophilic and thermophilic reactors treating cattle manure on a laboratory scale were compared. The rate of organic nitrogen degradation and phosphorus assimilation also increased with the temperature. Bodik *et al.* (2000) compared various types of anaerobic digesters (upflow anaerobic sludge blanket (UASB), upflow anaerobic filter and anaerobic suspended reactors), treating municipal wastewater under psychrophilic conditions (9—23℃). The upflow anaerobic filter and anaerobic suspended reactor were more effective than the UASB reactor. The comparison of anaerobic digestion of sewage sludge at different temperatures (20, 25 and 35℃) and retention times demonstrated that when the retention time decreased, the organic matter removal rate increased with temperature risen.

Temperature can influence the methanogenic bacteria activity, accordingly inhibiting the OFMSW degradation and stabilization efficiency. Temperature is the most important factor to anaerobic process (Ma, 2005; Wei *et al.*, 2004).

The purpose of this research was to verify the influence of temperature performance on the anaerobic treatment process of fermentable organic fraction of municipal solid waste in batch reactors, operating with high concentration of solid.

1 Materials and methods

The experimental system was set up and monitored in the National Engineering Research Center of Solid Waste Resource Recovery, located in Kunming City in southwest of China. The experimental system consisted of four anaerobic batch reactors of 2 L capacity each.

The reactors were loaded with the organic fraction of municipal solid waste (OFMSW), inoculated with the active sludge from the anaerobic digestion pool in Kunming wastewater treatment plant.

The waste, after being collected, was transported to the laboratory where it was ground and characterized physico-chemically. The operational parameters adopted for the experimental work are presented in Table 1.

Table1 Operational parameters of the reactors

Reactor	Parameters						
	$V_{reactor}$, L	T, ℃	Start-up pH	Inoculum, %	TS, %	TVS[a], %	C/N
A	2	25±1	7.5	20	17	83	25
B	2	35±1	7.5	20	17	83	25
C	2	45±1	7.5	20	17	83	25
D	2	55±1	7.5	20	17	83	25
E[b]	2	35±1	7.5	20	17	83	25
F[b]	2	55±1	7.5	20	17	83	25

Notes: a. Indicatates wt.% in total solid; b. experiment of fluctuation of temperature; TS. total solid; TVS. total volatile solid; C/N: the ratio of total organic carbon to total nitrogen

During biodegradation processes the following organic load factors were analyzed: total solid (TS) by the gravimetric method after drying at 105℃; total volatile solid (TVS) as a loss of weight between 105 and 450℃ (Krzystek *et al.*, 2001); chemical oxygen demand (COD) by the dichromate method, total organic carbon (TOC) (Model183 Instruments, China); total nitrogen by Kjeldahl (TKN) method volume of biogas produced by means of liquid level displacement at a fixed time each day; methane fraction of biogas, composition of pyrolytic and synthesis gases by gaseous chromatography (Chromatron GCHF 18.3, Germany); pH (digital pH meter, China); total volatile fatty (TVFA) by the distillation-titration method.

The performance of anaerobic reactors was analyzed after the organic matter had been degraded for 32 d.

The start-up pH value was adjusted to 7.5 by the addition of $Ca(OH)_2$ in NaOH in 1:1 weight ratio in reactors in order to make anaerobic digestion operate successfully. Based on the obtained data, the efficiency and results of anaerobic digestion were testified at different temperatures (25, 35, 45 and 55℃).

2 Results and discussion

2.1 Influence of temperature on the start-up time of anaerobic process

Degradation of substrate started almost immediately and proceeded smoothly in the reactors maintained at temperatures (35, 45 and 55℃). It is evident from Table 2 that the start-up time and aerogenous time of anaerobic digestion at 55℃ was shorter than that at other temperatures. The start-up time also indicated that biogas was ignited, namely the content of methane in biogas accounted for more than 50% (volume basis).

Table 2 Influence of temperature on the start-up time of anaerobic digestion

Temperature, ℃	25±1	35±1	45±1	55±1
Reactor	A	B	C	D
Aerogenous time, d	6.5	2	0.3	0.125
Start-up time, d	10	6	5.2	2

2.2 Influence of temperature on TS, TVS, COD, TVFA and alkalinity

The experiments performed in the four reactors at the same initial TS content of about 17% by weight, at temperatures 25, 35, 45 and 55℃. The effect of temperature on the anaerobic degradation process was tested. The increase of the process temperature from 25 to 55℃ had an advantageous effect on the reduction of organic load (Table 3). Meanwhile, TS reduction, TVS reduction and COD reduction increased with temperature rising.

Table 3 Operation results of the four reactors

Reactor	Parameters							
	COD reduction[a], %	TS reduction[b], %	TVS reduction[c], %	Biogas production, ml/g TS	Biogas production rate, ml/g TSd[d]	CH_4, %	TVFA, mg/L	Alkalinity, mg/L
A	31.4	24.6	35.5	48.6	1.52	65.2	1153	2100
B	44.0	48.1	53.2	113.2	2.76	66.4	868.0	1620
C	43.1	37.7	42.6	152.2	4.76	66.6	982.0	1980
D	57.1	48.6	59.8	159.7	4.99	70.0	943.0	1820

Notes: [a] COD reduction in the reactors was calculated on the basis of COD concentration in the reactors feed; [b] TS reduction in the reactors was calculated on the basis of TS concentration in the reactors feed; [c] TVS reduction in the reactors was calculated on the basis of TVS concentration in the reactors feed; [d] TSd is the total solid per day

Under the high temperature conditions anaerobic digestion excelled at TS reduction, TVS reduction, COD reduction, improving cumulative biogas productions, biogas production rate and substrate utilization efficiency. The results of this study also demonstrated that the variation of TS, VFA, alkalinity, pH, and biogas production with time during the batch anaerobic digestion of organic fraction of municipal solid waste followed the same pattern at mesophilic and thermophilic temperatures.

2.3 Influence of the fluctuant temperature on the biogas production variation

Anaerobic digestion was sensitive to temperature that fluctuated sharply, which gave rise to the instability of digestion system and broke the balance of concerted action of several groups of microorganisim, and even resulted in stopping the anaerobic process, accordingly inhibiting the OFMSW biodegradation. Therefore, the water-bath was adopted in order to maintain the constant temperature of the anaerobic process. Relative biogass production was used for indicating the influence on the anaerobic digestion. The experimental results of both reactor E and F revealed that thermophilic anaerobic digestion was more sensitive to temperature than mesophilic anaerobic digestion (Fig.1a, b). As a result of that the fluctuant temperature the biogass production decreased, and even stopped. The fluctuant temperature, however, could not bring about the irreversible influence on the anaerobic process. Namely, the influence of the instantaneously fluctuant temperature on the anaerobic process was temporary. Once the temperature resumed, the digestion efficiency came back accordingly. The reversion of digestion efficiency could be prolonged on the condition that time of fluctuant temperature was longer.

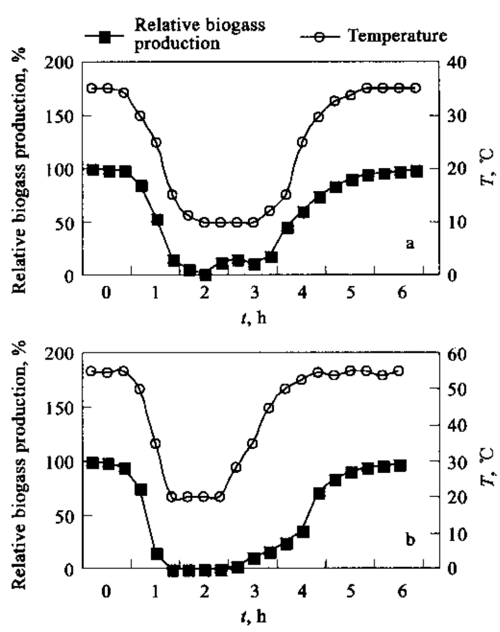

Fig.1 Relative variation of biogas production for changing temperature
a. reactor E (35—10℃); b. reactor F (55—20℃)

2.4 Influence of temperature on biogas production

Generally, the higher temperature was, the quicker biogas production rate was, and the shorter digestion time was, which was nonlinear relations between temperature and biogas production rate. The speed limit of anaerobic process was methanogenic phase where methanogenic bacteria had the differently optimum temperatures. The results indicated that the increase of temperature was in accordance with a linear increase of biochemical velocity under the mesophilic temperatures (30—37℃). Therefore, the optimum temperature adapting to methanogenic bacteria was around 35℃, while biogas production and biochemical velocity taking on direct correlativity. Thermophilic temperatures around 55℃was the other one which suited the methane-forming microorganisms growth, resulting in biogas increasing.

At low temperature conditions, the biogas production from anaerobic reactors for treating municipal solid waste was lower whose cumulative biogas production and biogas production rate was 8757 ml and 1.52 ml/g TSd respectively. 90% of cumulative biogas production appeared on the 27 d.

Fig.2a, b, c show that biogas yields under high temperature were better than those under low temperatures. Furthermore, methane concentration in the biogas was above 65% in four reactors (reactor A, B, C, D).

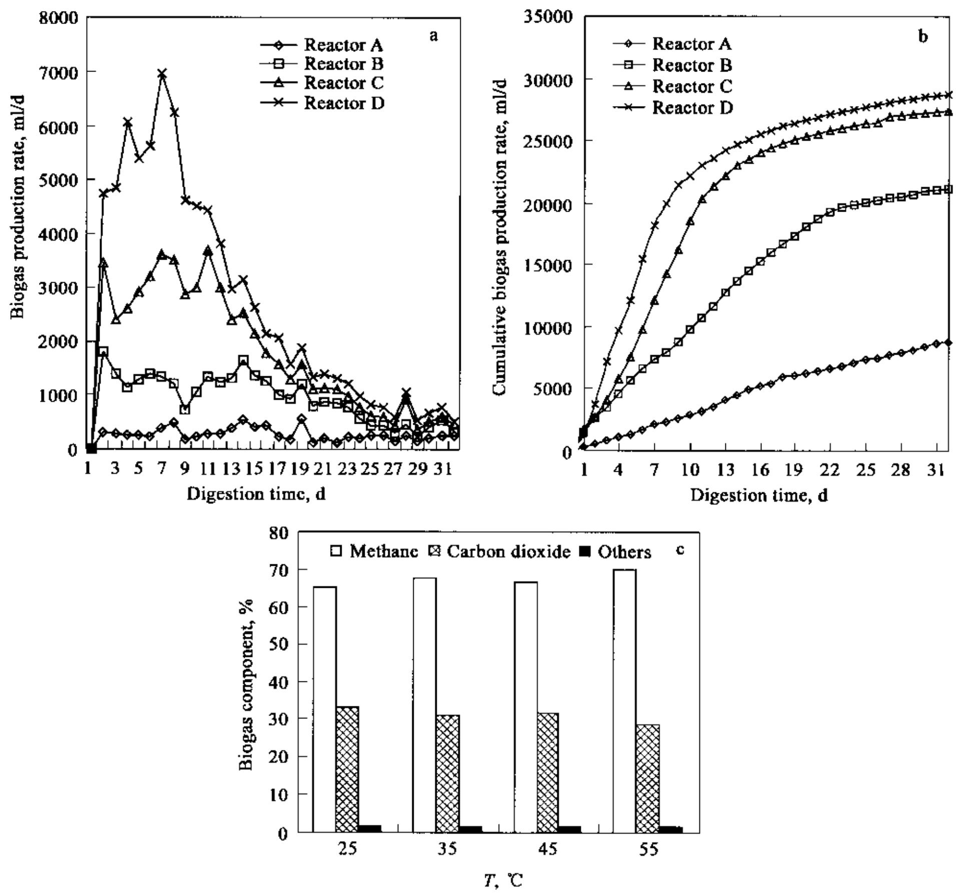

Fig.2 Influence of temperature on biogas production rate(a); cumulative biogas production(b) and biogas composition(c)

The biogas production rate was slow at the low temperature (25℃). Therefore, the digestion period was long, which the peak of biogas production was found on the day 18. Even though the digestion had been for 26 d, there was a few biogas produced from digesters. While under the mesophilic temperature (35—45℃) conditions, the peak of biogas production appeared on the day 3. Subsequently, the cumulative biogas production exceeded 1000 ml in a week, whose digestion period was around 30 d. The biogas production rate was higher at thermophilic temperature (55℃) than that at low temperature. The digestion period was about 20 d, whose peak of biogas production was found on the day 3. It can be concluded that the biogas production rate increased and reached a certain peak value in the range of temperatures, which showed that anaerobic process was characteristic of periodicity. Microorganism adapted themselves to the fluctuant temperature. These phenomena accorded with the three-phase theory of anaerobic digestion.

At the low temperature condition microorganism was lack of activity, which resulted in biodegrading municipal solid waste slowly and prolonging the digestion period. The activity of microorganism increased with the raise of temperature, which biodegraded substrate quickly, so the peak of biogas production appeared early.

The effect of anaerobic digestion at 35℃ was as much as that at 45℃ because the optimal temperature (35℃) was suitable for the methanogenic bacteria activity.

2.5 Influence of temperature on TKN content in anaerobic process

Influence of temperature on total kjeldahl nitrogen(TKN) content of anaerobic process was weak at 25, 35, 45 and 55℃. From Fig.3, it can be seen that TKN content varied with digestion time. During the digestion metaphase (about on the day 18) TKN content decreased appreciably. TKN was decomposed intensively into ammonia which disappeared because of the biogas transpiration. However, during the digestion, anaphase TKN content increased appreciably as a result of the transpiration of carbon dioxide and water, and the reduction of digestion. The digested residues became smaller and smaller; and it resulted in relatively concentrated TKN (Charest and Beauchamp, 2002). C/N was most often used to indicate both the stability of organic matter and the quality of the digested substrate for its further utilization. C/N ratio of digested substrate in the range 15 :1—17 :1 was considered to be stable and high quality compost (Molnar and Bartha, 1988). Table 4 and Fig.3 show that the composition of the digested residues may be utilized respectively as compost or biofertilizer.

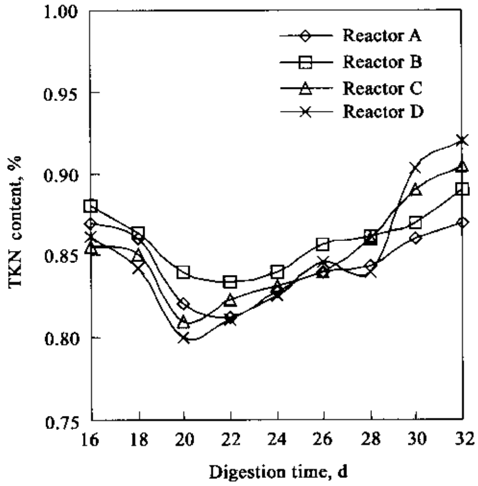

Fig.3 Influence of temperature on TKN content in the anaerobic process

Table 4 Influence of temperature on C/N

Parameter	Reactor A		Reactor B		Reactor C		Reactor D	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
C/N	25	16.6	25	12.6	25	131	25	11.9

3 Conclusions

From the results, it can be concluded that digesters should preferably be run at temperature (35℃, 55℃) with a digestion time close to 32 d for optimum energy yield. Reactor B (at 55℃) was the best biodegradation and bioprocess conversion efficiency among reactors, where TS reduction, TVS reduction, COD reduction and biogas production was 48.6%, 59.8%, 57.1% and 159.7 ml/gTS respectively. Methane concentration in the biogas was above 65% in four reactors. Temperature affects the flow direction and intermediate of OFMSW, consequently affecting biogas composition, yields and so on.

The low C/N weight ratio (15—17) in the digested substrate indicated that it can be utilized as biofertilizer or soil conditioner. However, the effluent COD concentration indicated that it should be treated before use for other purpose.

Further study should be required to determine the effect of winter season temperatures on biogas production and enhancement of gas production rates during winter at higher temperatures provided by a non-conventional energy input such as a solar greenhouse.

The results indicated that temperature had a significant influence on anaerobic process.

Acknowledgements: The authors are grateful to co-workers from National Engineering Research Center of Solid Waste Resource Recovery of China for their assistance in the experiments and also like to thank Dr. Zhang Mingji from the University of Kansas for proof reading of the manuscript.

References:

Bertolini G, 2000. Waste generation and markets: world, Europen Community and France. International solid waste association (ISWA) world congress [R]. ISWAAGHTM, Denmark: Copenhagen, 101—107.

Bodik I, Herdova B, Drtil M, 2000. Anaerobic treatment of municipal wastewater under psychrophilic conditions [J]. Bioprocess Engineering, 22: 385—390.

Braber K, 1995. Anaerobic digestion of municipal solid waste: a modern waste disposal option on the verge of breakthrough [J]. Biomass Bioenergy, 9(1-5): 365—376.

Charest M, Beauchamp C, 2002. Composting of de-inking paper sludge with poultry manure at therr nitrogen levels using mechanical turning—Behavior of physical-chemical parameters [J]. Bioresource Technology, 81: 7—17.

Chugh S, Chynoweth D P, Clarke W *et al.*, 1999. Degradation of unsorted municipal solid waste by a leach-bed process [J]. Bioresource Technology, 69: 103—115.

Gallert C, Bauer S, Winter J, 1998. Effect of ammonia on the anaerobic degradation of protein by mesophilic and thermophilic biowaste

[J]. Application Microbiology Biotechnology, 50: 495—501.

Gallert C, Winter J, 1997. Mesophilic and thermophilic anaerobicdigestion of source-sorted organic wastes: effect of ammonia on glucose degradation and methane production [J]. Application Microbiology Biotechnology, 48: 404—510.

Hinrich H, Henrik B M, Birgitte K *et al.*, 2004. Efficiency of the anaerobic treatment of the organic fraction of municipal solid waste: collection and pretreatment [J]. Waste Management & Research, 22: 35—41.

Kayhanian M, 1995. Biodegradability of the organic fraction of municipal solid waste in a high-solids anaerobic digester [J]. Waste Management & Research, 13: 123—136.

Kettunen R H, Rintala J A, 1997. The effect of low temperature (5—20℃) and adaptation on the methanogenic activity of biomass[J]. Application Microbiology Biotechnology, 8: 570—576.

Krzystek L, Ledakowicz S, Kahle H J *et al.*, 2001. Degradation of household biowaste in reactors [J]. Journal of Biotechnology, 92: 103—112.

Lema J M, Omil F, 2001. Anaerobic treatment: a key technology for a sustainable management of wastes in Europe [J]. Water Science Technology, 44(8): 133—140.

Lopes W S, Leite V D, Prasad S, 2004. Influence of inoculum on performance of anaerobic reactors for treating municipal solid waste[J]. Bioresource Technology, 94: 261—266.

Ma X P, 2005. Anaerobic microbiology and waste water treatment[M]. Beijing: Chemical Industry Press. 171—174.

Mackie R J, Bryant M P, 1995. Anaerobic digestion of cattle waste at mesophilic and thermophilic temperatures [J]. Application Microbiology Biotechnology, 43: 346—530.

Molnar L, Bartha I, 1988. High solids anaerobic fermentation for biogas and compost production[J]. Biomass, 16: 173—182.

Qiao W, Zeng G M, Yuan X Z *et al.*, 2004. Multi-factor study of anaerobic digestion on treatment for municipal solid waste [J]. Science and Technology, 27(2): 3—4.

Sakai S, Sawell S E, Chandler A J *et al.*, 1996. World trends in municipal solid waste management [J]. Waste Manage, 16(5/6): 341—350.

Sa'nchez E, Borja R, Weiland P *et al.*, 2000. Effect of the temperature and pH on the kinetics of methane production, organic nitrogen and phosphorus removal in the batch anaerobiodigestion process of cattle manure[J]. Bioprocess Engineering, 22: 247—252.

Sosnowski P, Wieczor ek A, Ledakowicz S, 2003. Anaerobic co-digestion of sewage sludge and organic fraction of municipal solid wastes [J]. Advances in Environmental Research, 7: 609—616.

Sung S, Santha H, 2003. Performance of temperature-phased anaerobic digestion (TPAD) system treating dairy cattle wastes [J]. Water Research, 37: 1628—1636.

Yu H W, Samani Z, Hanson A *et al.*, 2002. Energy recovery from grass using two-phase anaerobic digestion [J]. Waste Management, 22: 1—5.

Vavilin V A, Lokshina L Y, Ritov S V *et al.*, 1998. Modeling low-temperature methane production from cattle manure by an acclimated microbial community [J]. Bioresource Technology, 63: 159—167.

Vavilin V A, Lokshina L Y, Ritov S V *et al*, 2000. Description of two-steps kinetics in methane formation during psycrophilic H_2/CO_2 and mesophilic glucose conversion [J]. Bioresource Technology, 71: 195—209.

Zeng G M, Qiao W, Yuan X Z *et al.*, 2003. Complete mix anaerobic digestion treatment for municipal solid waste [J]. Journal of Hunan University(Natural Sciences), 30(5): 51—54.

(Received for review September 21, 2005. Accepted December 1, 2005)