Original Paper
Special articles: Asian Conference on Biomass Science
特集：アジアバイオマス科学会議

The Start-up of Thermophilic Anaerobic Digestion of Municipal Solid Waste

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(Received November 24, 2015)

Thermophilic anaerobic digestion of municipal solid wastes (MSW) was conducted for 6 weeks in a lab-scale semi-continuous digester for investigating the start-up operation of anaerobic digestion treating MSW. The feedstock was a mixture of simulated food waste, paper waste, and in some cases, cow manure. Organic loading rate (OLR) was adjusted 1.14 ～ 4.00 gVS/kg-sludge/day to biogas production. At the initial stage of thermophilic anaerobic digestion, pH value gradually increased from 8.2 to 8.3 on 17th day from start-up. Free-ammonia concentration in the digester also gradually increased from 361.6 to 412.5 ppm. On 17th day, inhibition of free-ammonia occurs, and biogas generation stopped. After gas generation stopped on day 17, pH and free-ammonia concentration were adjusted to the proper level by adding paper and deionized water. As a result, gas generation restarted on day 21. Then the amount of food waste charged in the digester was decreased and that of paper waste was increased to adjust the total amount of nitrogen invested in the digester. Afterwards, pH value was settled around 7.8, and a stable digestion was achieved till the end of experiment. Inhibition of free-ammonia could be suppressed by adjusting the amount of nitrogen invested in the digester.

都市ごみ(MSW)の高温嫌気性消化発酵(メタン発酵)立ち上げ時の実験条件を調べるために,半連続発酵方法を用いて6週間(1期：1～20日，2期：21～46日）メタン発酵が行われた。生ごみ，紙ごみ，そして牛ふん（立ち上げ時）を混合して発酵原料として供試した。有機物負荷量を，1.14～4.00 VS（有機物濃度）/kg-sludge/day に調製した。高温（52℃）メタン発酵の初期段階（実験開始から17日目）で，発酵液の pH は 8.2 から 8.3 に増加し，遊離アンモニア阻害が生じ，バイオガス生成は停止した。17日目以降，紙ごみとイオン交換水を用いて発酵液の pH と遊離アンモニア濃度を適性値に調整した。その結果，21日目以降，ガス生成が再び始まった。発酵液の全窒素濃度を調整するために，生ごみ量を減らし，紙ごみ量を増やして原料を供給して発酵試験を進めた。pH は 7.8 付近を推移，試験終了まで安定的に発酵が行われた。遊離アンモニアによる阻害は，発酵液における窒素量を制御することにより抑えられると考えられる。

Key Words
Free ammonia, Methane, Production rate

1. Introduction

The catastrophic earthquake that occurred at the northeast coast of Japan on Marth 11, 2011 had a great effect on Japanese energy policy. Developing the renewable energy is strongly required instead of nuclear power [1]. Anaerobic digestion of MSW is grabbing attention in Japan due to its stability compared with other renewable energies like wind power or solar power. Particularly, thermophilic anaerobic digestion of organic solid waste is superior in terms of hydrolysis speed and durability against high OLR [2]. Considering the practical use of thermophilic anaerobic digestion as a renewable energy, a large amount of food waste and paper waste generated in commercial facilities are usable as the feedstocks. Currently, utilization ratio of food waste is only 20% [3], and increasing recycling ratio is needed. There are a lot of literatures of co-digestion using cow manure or sewage sludge with food waste [4] because cow manure and sewage sludge are favorable ingredient in

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terms of containing abundant essential trace elements and methanogens. However, based on the assumption to use cow manure or sewage sludge, reactor must be located near stock farms or waste water treatment plants in the suburbs. Conveying MSW generated in city to suburb is so costly. There are few literatures to invest anaerobic digestion treating MSW without cow manure or sewage sludge. In this study, two types of feedstock were tested, and the co-digestion characteristics of the mixtures of MSW with or without cow manure were studied.

2. Experimental

Semi-continuous experiment with separable round-bottom flask as a reactor was carried out along 46 days at 52 °C. Within this approach, two mixtures of organic solid waste were tested, corresponding to periods Phase 1 (day 0 ～ 21) and Phase 2 (day 21 ～ 46). Table 1 shows the characteristics of feedstock. OLR was adjusted 1.14 ～ 4.00 gVS/kg-sludge/day to biogas production. The inoculum had been obtained from thermophilic anaerobic digester in Betsukai, Hokkaido, and bred in our lab. Feedstock was supplied to the reactor when the gas generation settled, and same amount of the digester was pulled out at the same time. pH was measured by pH meter at feeding time. Biogas production and biogas composition were determined by wet gas meter and gas chromatography. VFA and ammonia concentration were measured by distillation method. VFA is intermediate product of anaerobic digestion, and is essential for methane gas production, though it can be inhibitor if there are excess amount. Free-ammonia (NH_3) has been suggested as the important factor causing ammonia inhibition [5], and its concentration was calculated from the equilibrium relationship:

$$[NH_3] = \frac{[T-NH_3]}{(1+\frac{H^+}{k_a})}$$

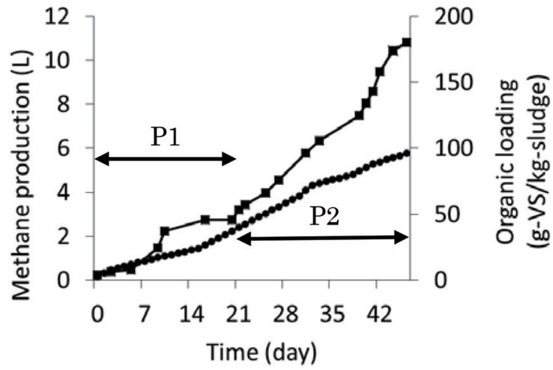
where $[NH_3]$ and $[T\text{-}NH_3]$ are the free and the total ammonia concentrations, respectively, and ka the dissociation constant, with the value of 34.4・10-10 at 52 °C [5].

Table 1 The characteristics of feedstock

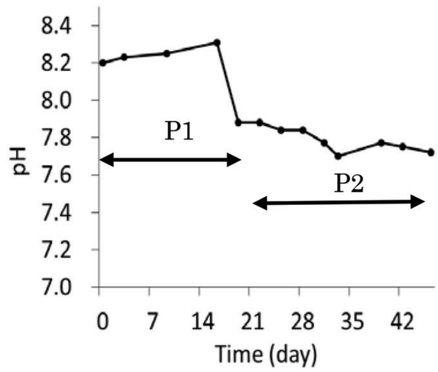
	Phase 1 (day 1 ～ 20)	Phase 2 (day 21 ～ 46)
Ingredient	Model food waste paper Cow manure	Model food waste paper Deionized water
TS (%)	33.5	15
VS (%)	30.6	13.6
C/N (approx.)	36	98
TKN (ppm)	6085	825

3. Results and Discussion

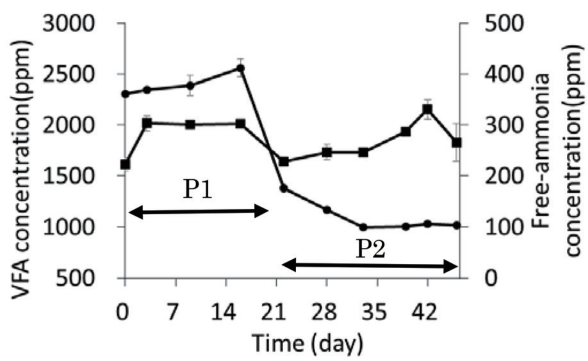
Fig. 1 shows the courses of anaerobic digestion. Biogas generation was once stopped day 17 ～ 20 in phase 1 (Fig. 1 (a)). pH value gradually increased from 8.2 to 8.3 on 17th day from start-up (Fig. 1 (b)). After gas generation stopped on day 17, pH and free-ammonia were adjusted to the proper level by adding paper and deionized water. As a result, gas generation restarted on day 21. In phase 2, no inhibition was observed from measured factors, and stable digestion was achieved without cow manure or



(a) Cumulative methane production and cumulative organic loading (■: methane production, ●: organic loading)



(b) pH



(c) VFA and free-ammonia concentration (■: VFA concentration, ●: free-ammonia concentration)

Fig. 1 The courses of anaerobic digestion sewage sludge. Methane production rate (L-CH_4/gVS) were 0.08 (phase 1) and 0.14 (phase 2). VFA concentration was relatively high throughout the experiment (around 2000 ppm as acetate) (Fig. 1 (c)). Free-ammonia concentration gradually increased from 361.6 to 412.5 ppm during Phase 1, and remained stable (around 100 ppm) during Phase 2. Free-ammonia concentration and pH value gradually increased during Phase 1, and biogas generation stopped at the end of Phase 1. These factors decreased during Phase 2 due to dilute the reactor and change the feedstock, and so biogas generation was stable till the end of Phase 2. Strong inhibition by ammonia occurred at the end of Phase 1 (NH_3 = 412.5 ppm). Angelidaki (1993) investigated the relationship between free-ammonia concentration and relative growth rate [5]. Considering our results using Angelidaki's data, the free-ammonia concentration of 412.5 ppm decreases relative growth rate to below 30 % and 70 % for the acetate-utilizing and hydrogenotrophic methanogenic bacteria, respectively. C/N ratio is a factor used for calculate OLR of anaerobic digestion treating wet feedstock. C/N ratio is usually adjusted in 20 ～ 30 [5] to prevent inhibitions of VFA and free-ammonia. In this study, the mixtures of feedstock of high C/N ratio was used (approximately 36 (phase 1) and 98 (phase 2): calculated using literature values [6)～8)]), in other words, the nitrogen concentration of feedstock was enough low to prevent inhibition by free- ammonia, but actually, inhibition by free-ammonia occurred in phase 1. Because of no dilution with deionized water, total kjeldahl nitrogen (TKN) concentration was relatively high (6085 ppm), though C/N ratio was proper level in phase 1. Nitrogen concentration in anaerobic digester treating high-solid organic waste tends to be high because the moisture content compares low with liquid anaerobic digestion. In case of anaerobic digestion treating high-solid MSW, nitrogen concentration in the feedstock should be taken note to prevent inhibition by ammonia, as well as C/N ratio.

4. Conclusion

Stable digestion was achieved during Phase 2, though inhibition was occurred during Phase 1. The mixture of model food waste and paper waste could be used as superior feedstock without cow manure or sewage sludge. Re-startup was possible by dilution of inhibition factors in the digester using paper and deionized water at the end of Phase 1. Nitrogen concentration in the feedstock should be taken care to prevent inhibition by ammonia, as well as C/N ratio, in case of anaerobic digestion treating high-solid MSW.

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