Quantitative Evaluation of Sodium Inhibition on the Anaerobic Digestion of the Organic Solid Wastes

Young – Chae Song, In – Soo Kim

Department of Marine Environmental Engineering, Korea Maritmie University, Puan, Korea

Abstract

The inhibitory effect of sodium ion on the anaerobic degradation of organic solid waste was studied by an anaerobic batch toxicity assay and inhibition model. The anaerobic degradation activity of food waste spiked with over 2g Na^+/L of sodium ion was severely inhibited at the initial stage of the exposure. The inhibition response of anaerobic microorganisms on the sodium ion estimated from the methane production was differed according to the concentration of sodium ion. The relative acclimation time(RAT) and methanation rate(RMR), defined as the ratios of initial lag time and maximum methane production rate of the sample spiked with sodium ion to the control, respectively, were used to evaluate the acclimation and inhibitory effects quantitatively on the anaerobic microorganisms. When sodium ion was increased from 2g Na^+/L to 20g Na^+/L, the RAT was exponentially increased from 18.9 to 90, but the RMR was linearly decreased from 0.97 to 0.02. The effects of sodium ion for the maximum methanation rate, first order kinetic constant and ultimate methane production were well evaluated by a generalized nonlinear expression model, it could be described by the uncompetitive inhibition model. The sodium ion concentration causing 50% inhibition of methanation activity was about 11g Na^+/L, and the critical sodium ion beyond to compelete inhibition was 20 to 21g Na^+/L. The presented results could be used to obtain the design or operation parameters of the anaerobic process treating food waste of high salt.

1. Introduction

Over 8 million tons of food wastes are produced in Korea annually, that amounts to around 60% of total organic fraction in municipal solid wastes(MOE, 1993). The wastes cause the various sanitary problems such as odor and pathogens as it is mainly composed of putrescible matters including grain, vegetable, and meat(Shin, et al., 1992). Anaerobic digestion is considered as a viable and economical alternative for food waste treatment, as it has low calorific value and high moisture content for incineration(Shin, et al., 1992 and 1995a). However, the food wastes contain the high concentration of sodium ion ranged from 2 to 3 g Na^+/L according to collection methods. The dry digestion process, which can minimize the supply of additional dilution water, is commonly used for this type wastes, resulting in the accumulation of sodium ion.

Numerous studies have been done to investigate the effects of elevated concentration of sodium ion on anaerobic digestion(McCarty & Mckinney, 1961 ; De Baere, et al., 1984 ; Rinzema et al., 1988). They reported that the methanogenic activity was decreased by 50% at 6,000－8,700mg Na^{+}/L, while the low concentration of sodium ion was an essential to growth of anaerobic microorganisms(De Baere, et al., 1984 ; Rinzema, et al., 1988 ; Field, et al., 1991). The food wastes are composed of various complex organics of high molecular as well as other inhibitory cations such as alkaline or alkali metals(Shin, et al., 1995b). The existence of various substances makes it difficult to predict the effect of sodium ion on the anaerobic digestion.

In this study, the inhibitory characteristics of sodium ion on the anaerobic degradation of food waste were investigated using anaerobic toxicity assay, and the effect on the kinetic parameters including the ultimate methane production, the first order kinetic constant and the maximum methane production rate were also estimated by a generalized non－linear inhibition model. The findings can be used as the basic data for the design and the operation of methane fermentation processes treating food wastes.

2. Materials and Methods

2.1 Characteristics of Substrate

The major components of food wastes including grain, vegetable, and meat were obtained from a restaurant. They were then freeze－dried, crushed to less than 2mm, and stored at 0 ℃. For the experiment, the food waste components were assembled according to the general composition of food wastes(grain : vegetable : meat＝0.39 : 0.21 : 0.4, on dry basis). The ratios of VS/TS and COD/VS were 0.88 and 1.2.

2.2 Anaerobic Toxicity Assays

The sodium ion toxicity on the anaerobic degradation of food wastes was evaluated in 600 mL bottle reactors sealed with silicon stoppers kept in place with screw caps. Into the reactor, substrate, anaerobic medium, and inoculum were added according to the procedure of anaerobic biodegradability test described in previous study(Shin et al., 1995b, c). The initial concentration of substrate was around 2,000mg VS/L. Anaerobic medium was made of phosphate buffer, mineral salts and trace metals according to Shelton and Tiedje(1984). The inoculum obtained from a mesophilic sewage sludge digester was added to the reactor by about 25% of the effective volume(300mL). Six different sodium chloride concentrations in the range of 0 to 20g Na^{+}/L were added to each reactor. The initial pH was adjusted to 7.2－7.5 with concentrated HCl or NaOH, and the reactor was flushed with nitrogen gas for 10min before capping. The reactors were incubated at 35℃ in a shaded rotary shaker with speed of 80rpm. The reactor added with only inoculum was also operated as a blank at the same condition.

2.3 Analysis

Gas was intermittently sampled by introducing the needle of a glass syringe to a silicon stopper. Methane content of the biogas was analyzed using a gas chromatography(Gow－Mac, series 580) equipped with a thermal conductivity detector. The net production was obtained by subtracting the methane produced in inoculum control from that in the study reactor, and by adjusting converted to standard temperature and pressure(Shin, et al., 1994, 1995c). Methane productions from the wastes based on one gram of initial volatile solid were calculated in each reactor. At scheduled times, the pH of reactor was monitored, and the homogenized content of reactor was sampled. The VSS of the collected samples were determined according to Standard Methods(1985). The volatile fatty acids(VFA) having C_2-C_6 were then analyzed by the gas chromatography(model HP 5890) equipped with a flame ionization detector. The separation was achieved by a capillary column(HP-FFAP : 30m×0.53 mm×1.0μm) using 30 mL per min nitrogen as a carrier gas. The operating temperatures of the column, injector and detector were 100℃, 200℃ and 220℃, respectively.

2.4 Calculations

The anaerobic degradation course of organic wastes can be divided into two periods as follows(Llabres-Luengo and Mata-Alvarez, 1987). The first period is the time(t_d) to reach the maximum methane production, assuming microbial growth as a limiting factor. It is considered as an acclimatization time required to overcome the adverse environmental conditions caused by toxicants, etc. The second period is the time after t_d, which governed by the availability of limited substrate. Therefore, the anaerobic degradation process of food wastes in the second period was expressed by a first order kinetic model shifted by the acclimatization time(t_d) as follows :

$$B=B_0(1-e^{-k(t-t_d)}) \quad (1)$$

where B is the cumulative methane production(L CH_4/g VS), Bo the ultimate methane yield(L CH_4/g VS), k the kinetic constant(d^{-1}), and td is the initial lag time(day). These kinetic parameters were estimated by using a finite difference, non-linear technique to fit eqn(1) to the experimental data for cumulative methane productions.

In order to evaluate the inhibitory effect of sodium ion, the relative acclimation time(RAT) and the relative methanation rate(RMR) were defined as the ratios of the initial lag time and the maximum methane production rate of the sample spiked with sodium ion to those of the control as followings.

$$RAT=\frac{LT_s}{LT_c} \quad (2)$$

where LT_c and LY_s are the initial lag time(day) of the control and the sodium spiked sample.

$$RAR=\frac{MR_s}{MR_c} \quad (3)$$

where MR_c and MR_s are the maximum methane production rate of the control and the sodium spiked sample(L CH_4/g VS/d).

2.5 Kinetic Models for Sodium Inhibition

The inhibitory effect of sodium ion on anaerobic degradation can be expressed to its effect on the kinetic parameters as using a generalized non-linear inhibition model(Han & Levenspiel, 1988 ; Kim et al., 1994) :

$$NI=\left[1-\frac{I}{I^*}\right]^{n,m,p} \quad (4)$$

where I and I* are the sodium ion concentration of the sample and inhibition coefficient (g/L), respectively. The coefficients(n, m, and p) are the constants used to describe the exponential inhibitory effect of sodium ion on the kinetic parameters, correspond to the maximum methane production rate, the kinetic constant, and the ultimate methane production, respectively. The values of the kinetic parameters, which were obtained with the sodium ion concentrations, were used to estimate the coefficients(I*, n, m, and p) by adapting non linear curve fitting technique.

3. Results and Discussion

3.1 Inhibition Response to Sodium Ion

Effect on the Methane Production : In the control without any spike of sodium ion, the cumulative methane production was exponentially increased in 12 hrs, and more than 90% of the ultimate methane production was produced within 10 days(Fig. 1). The pH of reactor monitored during the operation time showed a tendency to increase within the range of 7.2 to 7.5 as shown in Fig. 2. These indicate that the anaerobic toxicity assays were performed in a conditions, minimizing the reaction constraints caused by the microorganisms and the environments. Therefore, the effect of sodium ion on the anaerobic degradation of food wastes can be preferentially evaluated in the anaerobic toxicity assay.

The cumulative methane productions obtained under different concentrations of sodium ion showed the shape of an exponential function having initial lag period(Fig. 1). The inhibitory effect of sodium ion for the cumulative methane production increased with the increase of the concentration of sodium ion. However, as the sodium ion was increased from 2 to 10g Na^{+}/L, the ultimate methane production was

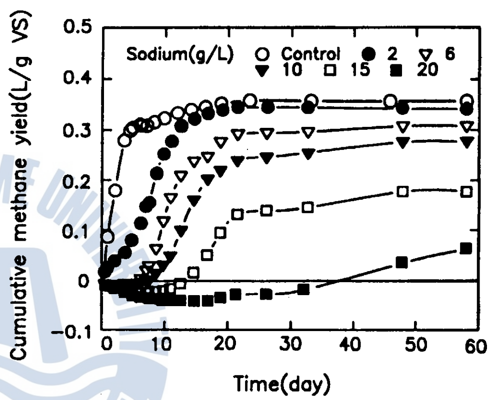

Fig. 1. Effect of sodium ion for cumulative methane production of food wastes.

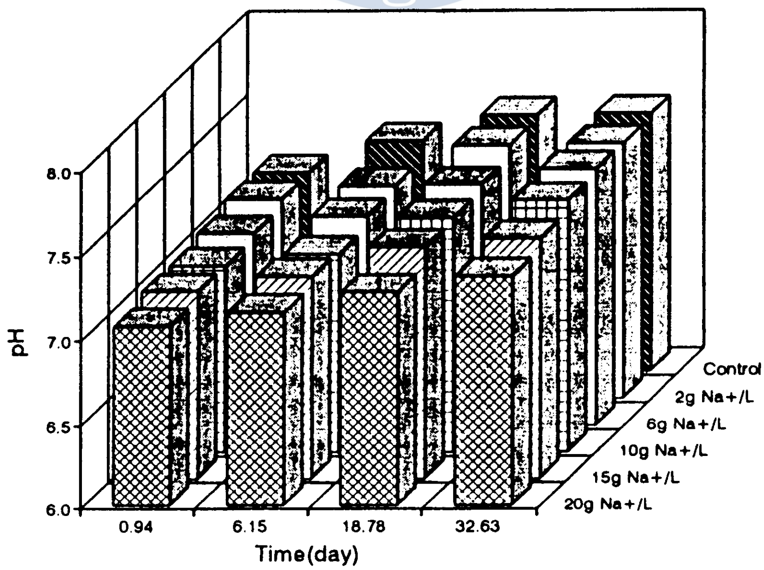

Fig. 2. pH profile for anaerobic degradation of food wastes with sodium ion.

not only reduced, but also lagged with the concentration of sodium ion. About 50% inhibition of ultimate methane production occurred at about 10g Na^{+}/L, that agreed with the previous study(Rinzema et al., 1988). At over 10g Na^{+}/L, the methane production in the beginning of operation was lower than that of the blank giving negative values, indicating severe inhibition on the unacclimated anaerobic microorganisms by the increased sodium ion(Battersby & Wilson, 1989).

This inhibition of the initial stage was gradually overcome with the operation time, due probably to the acclimation of anaerobic microorganisms to the inhibiting substance. Although the time required to overcome the initial stage inhibition was more extended at over 15g Na^{+}/L, the methane production was observed from the reactor with 20g Na^{+}/L. This fact mean that the activity of some methanogenic species can be maintained at the elevated sodium ion of 20g Na^{+}/L.

In previous studies, it was reported that the various species of substrate – specific anaerobic microorganisms have the different sensitivity to the inhibitory substance (Barnes & Fitzgerald, 1987 ; Hickey, et al., 1989 ; Lin, 1992 ; Kim, et al, 1994), and the sensitivity can be varied once adapted(Parkin, et al., 1983 ; De Baere, et al., 1984). Therefore, it is considered that the apparent acclimation and the inhibitory characteristics estimated by the cumulative methane production originate from the combined results of the effect of the anaerobic species to the sodium ion.

3.2 Inhibition response of Anaerobic Microorganisms

In order to predict the behavior of anaerobic degradation of food wastes under various concentration of sodium ion, the initial response pattern, acclimation, and inhibitory effects on the microorganisms were investigated by evaluating the production and the degradation of VFA and the waste hydrolysis in the batch reactors.

Initial response for the exposure : Fig. 3(A) shows the behavior of individual VFA in the batch reactors at the beginning stage of the operation. The total VFA of 13.7mM in the con-

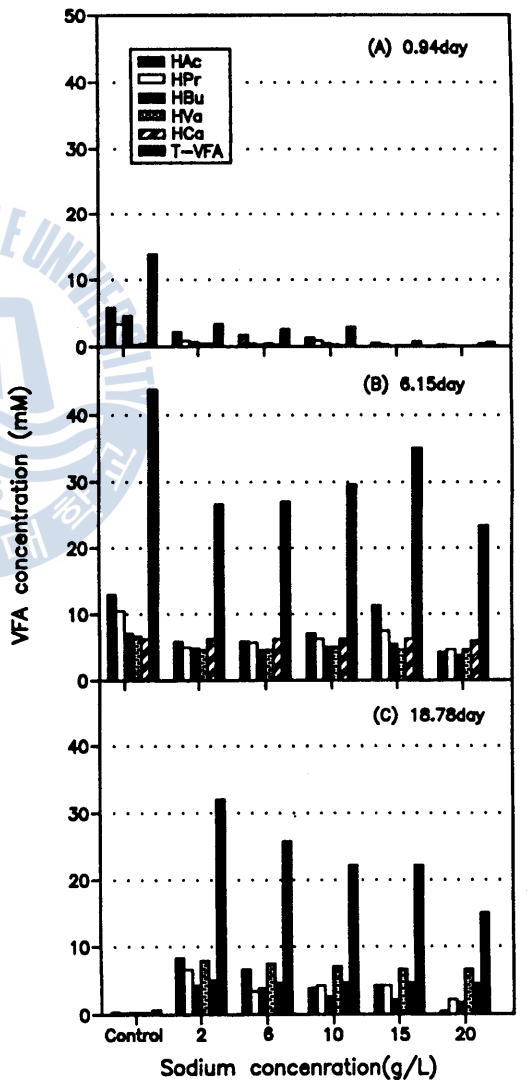

Fig. 3. Changes of VFA in the batch reactor dosed with sodium ion.

trol composed of 43.5% of acetic acid(HAc), 23.7 % of propionic acid(HPr), 32.2% of butyric acid (HBu) and less than 0.5% of the long chain fatty acids(LCFA) including valeric acid(HVa), caproic acid(HCa), which were mainly originated from the degradation of proteins or fats (Hanaki & Nagase, 1981 ; Elefsiniotis & Oldham, 1994). It implied that the degradation of meat component by an unacclimated microorganisms can be retarded in the initial stage of anaerobic degradation. However, when anaerobic microorganism was exposed to 2g Na^{+}/L, total VFA was only 3.3mM, indicating the inhibition of sodium ion on unacclimated anaerobic microorganisms. Of course, this inhibitory effect increased with the increase of sodium ion up to 20g Na^{+}/L. It was reported that the anaerobic microorganisms suddenly exposed to the sodium ion suffered a considerable environmental stress(Gaudy and Gaudy, 1980). Possibly, the inhibitory effect at the initial stage can be explained that the osmotic shock caused the shift in the metabolic processes such as the normal growth pattern of anaerobic microorganisms and the degradation of organic materials.

Adaption to Sodium Ion : Fig. 3(B) is the VFA behavior in the batch reactors after 6.15 day operation, and shows the course of acclimation of anaerobic microorganisms to the sodium ion. The total VFA of the control was 43.5mM much higher than the initial stage. The major products of acidification were HAc 29%, HPr 24%, and HBu 16.3%, and HVa and HCa were also increased to 15.7% and 14.2%, respectively. However, as sodium ion increased from 2 to 10g Na^{+}/L, total VFA also increased from 26.5mM to 29.6mM. On the other hand, the removal of VSS decreased with sodium ion as shown in Fig. 4, the molar percentage of HAc increased from 21.7% to 24%. This result can be explained by the fact that the acclimation of acetoclastic methanogens degrading HAc to methane was relatively retarded, while the HAc was consecutively produced from(βoxidation of LCFA of even number of carbon atoms such as HCa(Rinzema, et al., 1994). The molar percentages of HPr and HVa in this range of the sodium ion maintained at 21% and 17%, respectively, suggesting that the species degrading the VFA with odd numbered carbon were also slowly acclimated. At 15g Na^{+}/L, total VFA increased to 34.9mM, and the molar percentage of HAc was also high as 32.3%. However, the degradation efficiency of VSS was lower than 10%(Fig. 4), implying that acclimation of the hydrolytic microorganisms and acetoclastic methanogens were relatively retarded. At 20g Na^{+}/L, the total VFA was only 23.3mM, and the degradation efficiency of VSS was also quite low. It means that the hydrolysis step producing the monomers such as amino acid, sugar, and LCFA was retarded. The acclimation of anaerobic microorganisms for the inhibitory substance showed in the above results might be resulted from the adaptation of metabolic pathways to degradation of substrate under toxic conditions and/or colonization of inhibition – tolerant organisms(Parker, et al., 1992).

Inhibition to Sodium Ion : On the 18.8th day, the anaerobic microorganisms in the reactors except one with 20g Na^{+}/L should be adapted to the sodium ion considering the decrease of methane production rate(Fig. 1). Therefore, the inhibitory effect of sodium ion on the acclimated species can be evaluated from the VFA distribution at that time as shown in Fig. 3(C). In the control, the anaerobic degradation of food wastes was over 95% as shown in Fig. 1, while total VFA was less than 1mM. As the concentration of sodium ion increased from 2g Na^{+}/L to 15g Na^{+}/L, total VFA decreased from 32.2 mM to 22.0mM. The molar percentages of HVa and HCa increased from 24.0% and 15.7% to 30.9% and 21.1%, respectively, while the HPr and HBu maintained around 19.0% and 12.0%. On the other hand, HAc decreased from 25.1% to 18.9%. The results implied that acetoclastic methanogens acclimated to the sodium ion ranging from 2 to 15g Na^{+}/L, but LCFA degrading bacteria were more inhibited with sodium ion.

It was reported that methanogens had larger acclimating capacity to toxicants(Parkin, et al., 1983 ; De Baere, et al., 1984), and that some methanogens found in marine or brackish sediments were active at high sodium concentration of around 14g Na^{+}/L(Capone, et al., 1983). Hanaki(1981) reported that the accumulated LCFA can affect the obligate hydrogen producing acetogens, which were responsible for the β-oxidation of LCFA, as well as the activity of hydrogenotrophic and acetoclastic methanogenic bacteria. However, the high level of sodium ion did not alter the microbial populations(De Baere, et al., 1984). At 20g Na^{+}/L, the methane production rate increased on the 18.78th day, indicating that the acclimation of anaerobic microorganism was in progress. The total VFA was merely 15.1mM, while the molar percentage of

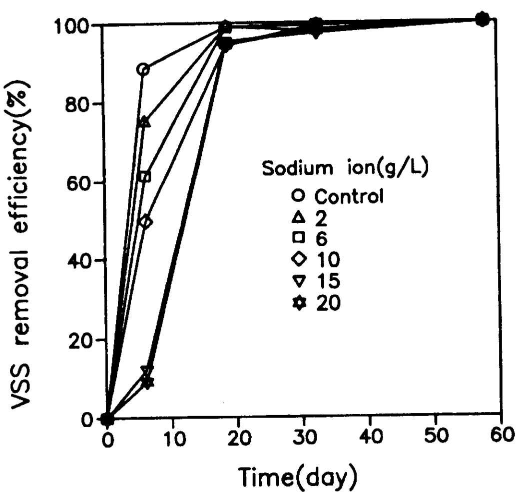

Fig. 4. Effect of sodium ion on the hydrolysis of food wastes.

the LCFA such as HVa and HCa were over 75.0%. However, the degradation of VSS was similarly high in comparison to the reactor with 15g Na^{+}/L. The fact indicated that anaerobic microorganisms responsible for the anaerobic oxidation or fermentation of hydrolysis products were severely inhibited at 20g Na^{+}/L. It can be concluded that the differences of the inhibitory characteristics of substrate-specific microorganisms responsible for the degradation of food wastes resulted in the apparent inhibition on the methane production.

3.3 Inhibition Model of Sodium Ion

Estimation of Kinetic Parameters : The kinetic parameters for the anaerobic degradation of food wastes are summarized in Table 1. When the concentration of sodium ion was increased, the inhibitory effect on these parameters also increased. The effects of sodium ion on the methanogenic activity and the acclimation of anaerobic microorganisms were quantitatively evaluated by the relative acclimation time(RAT) and methanation rate(RMR), which were defined as the ratios of initial lag time and maximum methane production rate of the sample spiked with sodium ion to the control(Fig. 5).

At 2g Na^{+}/L, the initial lag time was a higher value of 8.5 day, while it was only 0.45 day in the control. This initial response on the anaerobic microorganisms was due probably to the osmotic shock by the rapid change of the sodium ion. When the sodium ion was increased from 2 to 20g Na^{+}/L, the RAT was exponentially increased from 18.9 to 90. It implied that the start-up period of anaerobic process using unacclimated inoculum can be more extended by the higher concentration of sodium ion. However, the effect of sodium ion on the methanation estimated by the RMR was linearly decreased with the increase of sodium ion concentration.

Table 1. Inhibitory Effect of Sodium Ion on the Kinetic Parameters for Anaerobic Degradation of Food Wastes.

Sodium ion(g Na^+/L)	Control	2	6	10	15	20
B_0(L/g VS)	0.357	0.342	0.308	0.276	0.178	0.063
$k(d^{-1})$	0.318	0.311	0.240	0.198	0.197	0.040
$(dB/dt)_{max}$(L/g VS.d)	0.109	0.106	0.074	0.055	0.035	0.0025
t_d(d)	0.45	8.52	9.65	12.36	16.53	40.21

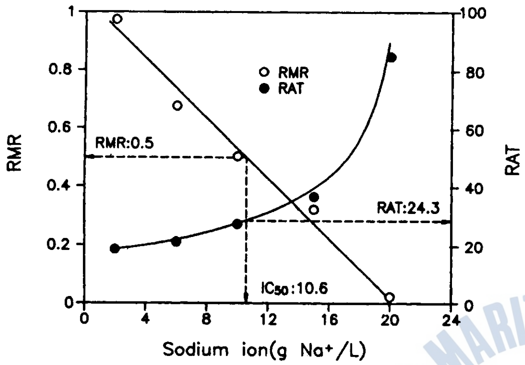

Fig. 5. Effect of sodium ion for RAT and RMR in anaerobic degradation of food wastes.

IC_{50}, which is the concentration of sodium ion causing 50% inhibition of methanation, was estimated to be about 10.6g Na^+/L from the RMR. In previous studies, it is reported that IC_{50} of the sodium ion can be differed within the range of 8 – 24g Na^+/L by the type or the operation conditions of the anaerobic process(Rinzema, et al., 1988).

Inhibitory Effect of the Sodium Ion estimated by the Inhibition Model : The inhibitory effect of sodium ion on the kinetic parameters including the maximum methane production rate ($(dB/dt)_{max}$), first order kinetic constant(k), and ultimate methane production(B_0) were evaluated by the proposed the inhibition model, and the inhibition coefficients including I*, n, m, and p were summarized in Table 2. The inhibition model was well fitted to all kinetic parameters as shown in Fig. 6 to Fig. 8. Fig. 6 shows the maximum methane production rate with the increase of sodium ion. The inhibition coef-

Table 2. Summary of Inhibition Coefficient of Sodium Ion for Food Waste Anaerobic Degradation

Parameter	Inhibition coefficient(I*)	Exponential coefficient
$(dB/dt)_{max}$	20.2	n=0.82
k	20.6	m=0.58
B_0	20.1	p=0.28

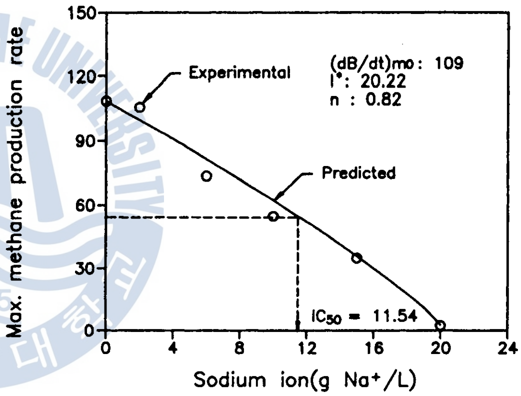

Fig. 6. Effect of sodium ion concentration on the maximum methanation rate.

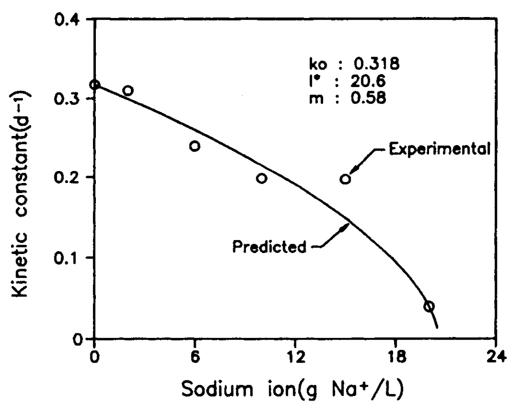

Fig. 7. Effect of sodium ion concentration on first order kinetic constant.

ficient(n) was 0.82, and the inhibitory effect increased linearly with sodium ion. However, the effect on the first order kinetic constant was more increased the higher concentration of sodium ion. The inhibitory effect of sodium ion on the ultimate methane production was rapidly decreased with the increase of sodium ion.

The inhibition constant(I*), which meant the critical sodium ion beyond the complete inhibition, was estimated to be from 20 to 21g Na^{+}/L for the three kinetic parameters.

Evaluation of the Inhibition Model : The conventional models of Haldane function type using inhibition constant have been used to estimate the effect of inhibitory substance on the anaerobic digestion(Barnes and Fitzgerald, 1987). Recently, the inhibitory effect was expressed as the function of inhibition term for the half velocity coefficient and the maximum substrate utilization developed by the Monod type models(Han & Levenspiel, 1988 ; Kim, et al., 1994). The inhibition term was generalized to the non – linear function as eqn(4), which can be satisfied most concerns for fit of experimental data and seems to be generally accepted.

In this research, because the anaerobic degradation kinetics of food wastes was evaluated by the first order model, the assumptions, i) the maximum methane production rate is in proportion to the maximum specific substrate utilization rate, ii) the maximum methane production rate can be expressed as the product of first order kinetic constant and ultimate methane production, were used to estimate the inhibitory effect of the wastes using the generalized non – linear expression for first order kinetics. The main advantage of this inhibition model is the prediction of the inhibition coefficient(I*) representing the inhibitory substance concentration beyond which all microbial activity ceases. The inhibition constants(I*) for maximum methane production rate, first order kinetic constant and ultimate methane production were 20.2, 20.6, and 20.1, respectively.

It indicates that the critical sodium ion concentration beyond the complete inhibition is in the ranged from 20 to 21g Na^{+}/L. The inhibitory effect estimated using the generalized non – linear model is expressed to the five types by the exponential curve depending on the exponential coefficients(n, m, p) as shown in Fig. 9. The exponential coefficient, n, for maximum methane production rate was 0.82, and it indicates that the maximum methane production rate decreases with the concentration of sodium ion like linear curve. However, the exponential coefficient, m, for first order kinetic constant was 0.58, and it means that the more inhibitory effect is appeared at the higher concentration of sodium ion. The maximum methane production rate divided by first order kinetic constant gives the ultimate methane production(Shin, et al., 1995b, c). Therefore, the exponential coefficient(p) for ultimate methane production can be theoretically calculated by the difference between n and m as 0.24. The value obtained by fitting the inhibition model to the experimental data was 0.28,

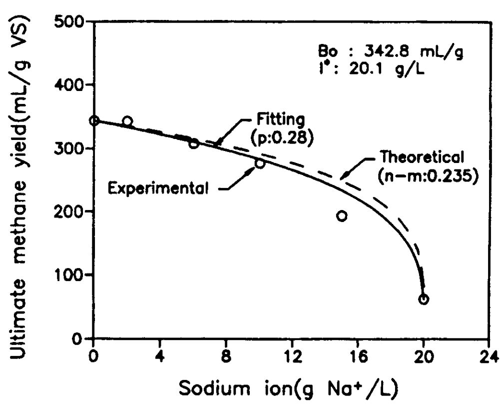

Fig. 8. Effect of sodium ion concentration on the ultimate methane yield.

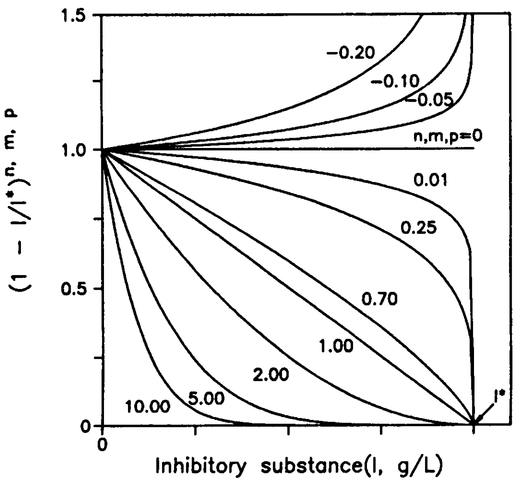

Fig. 9. Inhibitory characteristics of generalized non - linear inhibition model(for n, m, p ; i) <0 : stimulation, ii) 0 : non - inhibition, iii) 0<n, m, p<1 : slightly inhibition, 1 : linear inhibition, >1 : severely inhibition)

and the difference between two values was acceptable(Fig. 7).

The inhibitory effect for specific substrate utilization rate(k_{su}) and half velocity constant(K_s) in the model developed by Monod can be expressed by the inhibition terms as follow four cases. i) competitive, $k_{su}^* = 1.0$, $K_s^* > 1.0$, ii) non - competitive, $k_{su}^* < 1$, $K_s^* = 1.0$, iii) uncompetitive, $k_{su}^* < 1.0$, $K_s^* < 1.0$, and iv) mixed, $k_{su}^* < 1.0$, $K_s^* > 1.0$(Kim, et al., 1994). However, because the kinetic for anaerobic degradation of food wastes was expressed by the first order model, the understanding on the relationship between the Monod kinetic and first order kinetic are required to describe the inhibitory effect of sodium ion. In a batch reactor, the first order kinetic model can be related with the Monod equation by the following assumptions. i) the maximum substrate utilization is in proportion to the maximum methane production rate, ii) the available substrate is the limiting factor in the reaction.

$$-\frac{dS}{dt} = \frac{k_0 XS}{K_s + S} = kS \tag{6}$$

$$K_s = \frac{K_0 X}{k} \tag{7}$$

The inhibition terms for the first order kinetic constant(k*) and half velocity constant(Ks*) can be expressed as presented in eqn(8), and eqn(9).

$$\begin{aligned} k^* &= \left(\frac{dB}{dt}\right)_m \Big/ \left(\frac{dB}{dt}\right)_{mo} \\ &= k_{su}/k_{suo} \\ &= \left(1 - \frac{I}{I^*}\right)^n \end{aligned} \tag{8}$$

$$\begin{aligned} K_s &= \left(\frac{k_{su}X}{k}\right) \Big/ \left(\frac{k_{suo}X}{k_0}\right) \\ &= \left(\frac{(dB/dt)_m}{(dB/dt)_{mo}}\right) \times \left(\frac{k_0}{k}\right) \\ &= \left(1 - \frac{I}{I^*}\right)^{n-m} \end{aligned} \tag{9}$$

It means that the type of inhibition model for the maximum methane production rate and the ultimate methane production can be determined by the inhibition coefficients including n and p(=n - m). The n and p for anaerobic degradation of food wastes were estimated as 0.82($k^* < 1.0$) and 0.24($K_s < 1.0$), respectively. Therefore, the inhibitory effect of sodium ion on the anaerobic degradation of food wastes can be properly described as an uncompetitive inhibition model with the(dB/dt)max($n > 0$) and Bo($p > 0$) decreasing as the sodium ion was increased.

Anaerobic Digestion Design Implication : Sodium ion can be continuously accumulated up to a high concentration in a dry digestion process operating for the long term, resulting in the deterioration in performance of the system. The acclimatization time of anaerobic microorganisms was exponentially increased according to the concentration of sodium ion. However, because food wastes contain generally the low level of sodium ion of 3 - 5g Na^+/L, the start - up of the system using unacclimated inoculum can be performed successfully without any inhibitory problems. The degradation rate of food wastes is affected by high level of sodium ion, but of which effect to the ultimate methane production is relatively small. The effect of sodium is reversible(Field, et al., 1991), and dose not alter the microbial population(De Baere, et al., 1984). Therefore, the methods for the reduction of sodium ion concentration such as the pretreatment or the alteration of the waste collection can be recommended to efficient start-up of anaerobic digestion system. The high level of sodium ion accumulated in the long term operated digester might be diluted to obtain the proper process performance by the periodic substitution of the dilution water. The presented model for sodium inhibition on the anaerobic digestion of food wastes can be used to determine the period and the amount of the dilution water substitution.

4. Conclusions

1. The apparent inhibitory effects of sodium ion on the methane production can be observed from the retardation of the methane production and the reduction of ultimate methane production.
2. The species of anaerobic microorganisms responsible for the degradation of food wastes showed different characteristics of acclimation and inhibitory effect according to the concentration of sodium ion.
3. The effects of sodium ion on the maximum methanation rate, the first order kinetic constant and the ultimate methane production were properly evaluated by a generalized non-linear expression model, describing the uncompetitive inhibition model.
4. The sodium ion concentration, IC50, causing 50% inhibition of methanation activity was about 10g Na^+/L, and the critical sodium ion beyond the complete inhibition was a value ranged from about 21g Na^+/L. The presented results can be used to obtain the design or operation parameters in order to prevent the inhibitory effect of accumulated sodium ion in the anaerobic process treating food wastes.

5. Reference

1) APHA, AWWA, WPCF., Standard methods for the examination of water and wastewater. 16th ed. Washington, D.C.(1985).
2) Barnes, D., and P. A. Fitzgerald, "Anaerobic Wastewater Treatment Processes", *Environmental Biotechnology*, Forster, C., and Wase, D. A. J. (Eds.), Jhone Wiley, Toronto, pp. 57-113(1987).
3) Battersby, N. S. and Wilson, V., "Survey of the anaerobic biodegradation potential of organic chemical in digesting sludge", *Appl. Environ. Microbiol.*, 55(2), 433-439(1989).
4) Capone, D. G., Reese, D. D. and Kiene, R. P., "Effects of metals on methanogenesis, sulfate reduction, carbon dioxide evolution, and microbial biomass in anoxic salt marsh sediments", *Appl. Envir. Microbiol.*, 45, 1586-1591(1983).
5) De Baere, L. A., Devocht, M., Van Assche, P., and Verstraete, W., "Influence of high NaCl and NH_4Cl salt levels on methanogenic associations", *Wat. Res.*, 18(5), 543-548(1984).
6) Elefsiniotis, P. and Oldham, W. K., "Effect of HRT on acidogenic digestion of primary sludge", *J. of Environ. Enginr*, 120(3), 645-660 (1994).
7) Field, J., Sierra-Alvarez, R., and Lettinga, G., "Effect Wastewater Characteristic and Environmental Factors", *International Course on Anaerobic Wastewater Treatment*, Wageningen Agricultural University, June 26-August 7(1991).
8) Gaudy, A., and Gaudy, E., Microbiology for Environmental Scientists and Engineers, McGraw-Hill, Inc., pp. 618-663(1980).
9) Han, K., and Levenspiel, O., "Extended monod

kinetics for substrate, product, and cell inhibition", *Biotech. Bioeng.*, 32, 430 – 437(1988).

10) Hanaki, K., "Mechanism of inhibition caused by long chain fatty acids in anaerobic digestion process", *Biotech. Bioeng.*, 23, 1591 – 1610(1981).

11) Hickey, R. F., Vanderwielen, J. and M. S. Switzenbaum, "The effect of heavy metals on methane production and hydrogen and carbon monoxide levels during batch anaerobic sludge digestion", *Wat. Res.*, 23(2), 207 – 218,(1989).

12) Kim, I. S., J. C. Young, and H. H. Tabak, "Kinetics of acetogenesis and methanogenesis in anaerobic reactions under toxic conditions", *Wat. Environ. Res.*, 66(2), 119 – 132(1994).

13) Lin, C. Y., "Effect of heavy metals on volatile fatty acid degradation in anaerobic digestion", *Wat. Res.*, 26(2), 177 – 183(1992).

14) Llabrés – Luengo, P., and Mata – Alvarez, J., "Kinetic study of the anaerobic digestion of straw – pig manure mixtures", *Biomass*, 14, 129 – 142(1987).

15) McCarty, P. L., and McKinney, R. E., "Salt toxicity in anaerobic digestion", *J. WPCF*, 33(4), 399 – 415(1961).

16) MOE, 전국일반폐기물 발생 및 처리현황('92), pp. 5 – 6(1993).

17) Parker, W. J., E.R. Hall, G.J., and L. – A. Cornacchio, "Inhibitory effects of kraft bleachery effluents on methanogenic consortia", *Wat. Res.*, 26(7), 955 – 961(1992).

18) Parkin, G. F, Speece, R. E., Yang, H. J., and Kocher, W. M., "Response of methane fermentation systems to industrial toxicants", *J. WPCF*, 55(1), 44 – 53(1983).

19) Rinzema, A., Boone, M., Knippenberg, K. V. and Lettinga, L., "Bactericidal effect of long chain fatty acids in anaerobic digestion", *Wat. Environ. Res.*, 66(1), 40 – 49(1994).

20) Rinzema, A., Lier, J. V., and Lettinga, G., "Sodium inhibition of acetoclastic methanogens in granular sludge from a UASB reactor", *Enzyme Microb. Technol.*, 10, 24 – 32(1988).

21) Shelton, D., and Tiedje, J. M., "General method for determining anaerobic biodegradation potential", *Appl. Envir. Microbiol.*, 47, 850 – 857(1984).

22) Shin, H. S., et al., A Study on the Process Development for Anaerobic Digestion of Biodegradable Food Waste, Kolon Eng. Inc.(1992).

23) Shin, H. S., Moon, M. J., Lee, J. J., Chung, Y. J., Song, Y. C. and Bae, B. U., "Anaerobic Treatability of Food Waste with High Salt Concentration", *Proceedings of the 7th International Symposium on Anaerobic Digestion*, Cape Town (South Africa), 23 – 27 January, pp. 120 – 129 (1994).

24) Shin, H. S., et al., Organic Waste Recycling Technology, Owun Culture Foundation(1995a)

25) Shin, H. S., Song, Y. C., and Paik, B. C., "Effect of sodium ion on the anaerobic degradation of food waste : Quantitative evaluation, inhibition model", *J. of KOWRC*, 2(2), 3 – 17(1995b).

26) Shin, H. S., Song, Y. C. and Bae, B. U., "Anaerobic degradation characteristics of organic waste : methane conversion, kinetics, effect of the particle size", *J. of Korean Society of Environ. Engineers*, 17(3), 237 – 245(1995c).