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Compost of Swine Manure Slurry Using the Thermophilic Aerobic Oxidation (TAO) System

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Summary

A field-scale(8.6×2.5×2.4 m) and pilot-scale(1.39×0.89×0.89 m) thermophilic aerobic oxidation (TAO) units were installed to investigate the volume reduction efficiency of slurry, by varying the aeration and treatment temperature of swine manure, and the collected liquid was evaluated as a liquid fertilizer. In the field-scale unit, the aeration level and numbers of foam breakers made different effects on the slurry volume and temperature in the TAO system. The experiments were performed for three cases, using different levels of aeration and numbers of foam breakers: Treat-A (aeration rate; 120 m^3 air/hr using 2 air pumps and 2 foam breakers), Treat-B (aeration rate; 180 m^3 air/hr using 3 air pumps and 3 foam breakers) and Treat-C (aeration rate; 180 m^3 air/hr using 3 air pumps and 4 foam breakers). With the same input volume (5 m^3/day) of swine manure slurry, the resulting liquid levels, temperatures and evaporation rates were 50~100 cm, 31~64℃ and 55 ℓ/m^2/day for Treat-A; 40~90 cm, 29~52℃ and 75 ℓ/m^2/day for Treat-B; and 40~70 cm, 45~54℃ and 120.0 ℓ/m^2/day for Treat-C. In the pilot-scale unit, semi-continuous flow of swine manure slurry was introduced : 50 ℓ every 2hr (T-1), 50 ℓ every 3hr (T-2), 40 ℓ every 2hr (T-3) and 60 ℓ every 4hr (T-4) within 24 hours, in order to find the maximum slurry volume reduction conditions.

(**Key words** ; Evaporation, Slurry, Swine manure, Temperature, Thermophilic aerobic oxidation system)

INTRODUCTION

Waste treatment and composting methods have been developed and applied to minimize the pollution caused by livestock excretions. Several treatment processes have been used, such as a biological process, oxidation ditch, and the soil trench method, to name by a few. However, the treatment processes are difficult to apply because of the high concentrations of N, P and organic compounds in livestock excretions. Therefore, an integrated composting method, which uses solid and liquid livestock excretions, would be very practical and

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realistic for the management of livestock excretions (Lee, 1996).

The TAO system is a biological composting process that can be applied to a large spectrum of organic wastes, by utilizing auto-heating above 55℃. The TAO system is very effective at slurry volume reduction, production of a pathogen-free liquid fertilizer, and the removal of the malodor, which has been proven in both Korea and Japan. This study evaluates the TAO reactor as a composting system, and especially the optimal operating conditions for producing liquid fertilizer in the reactor.

MATERIALS AND METHODS

The field-scale unit experiments were performed using a reactor with a volume of 52 m^3 (8.6×2.5×2.4 m). The working volume was 21 m^3. The schematic diagram of this TAO reactor is shown in Fig. 1. The slurry was taken from a Korean pig farm, which has 1,000 pigs generating 4.5~5.0 m^3 manure slurry per day. The slurry was stored in a tank with a capacity of 8 m^3, and put into the reactor, at a height of 85~100 cm for each operation. Three ejection type pumps (60 m^3 air/hr) and 4 foam breakers (1,200 rpm) were installed inside the reactor. The pilot-scale unit experiments were conducted using a 1.1 m^3 (1.39×0.89×0.89 m) reactor, with a working volume of 0.6 m^3. One air pump and one foam breaker were installed inside the reactor. The slurry was filtered with a 200 mesh screen and then stored in a tank with a capacity of 2 m^3. Temperature sensors were placed inside the reactor at 50 and 120 cm from the bottom. An acrylic liquid gauge and a sampling valve were placed at the front of the reactor. An effluent valve, used to take samples of the efflux during the operation, was installed at the rear of the foam breaker.

In order to investigate the optimal operating

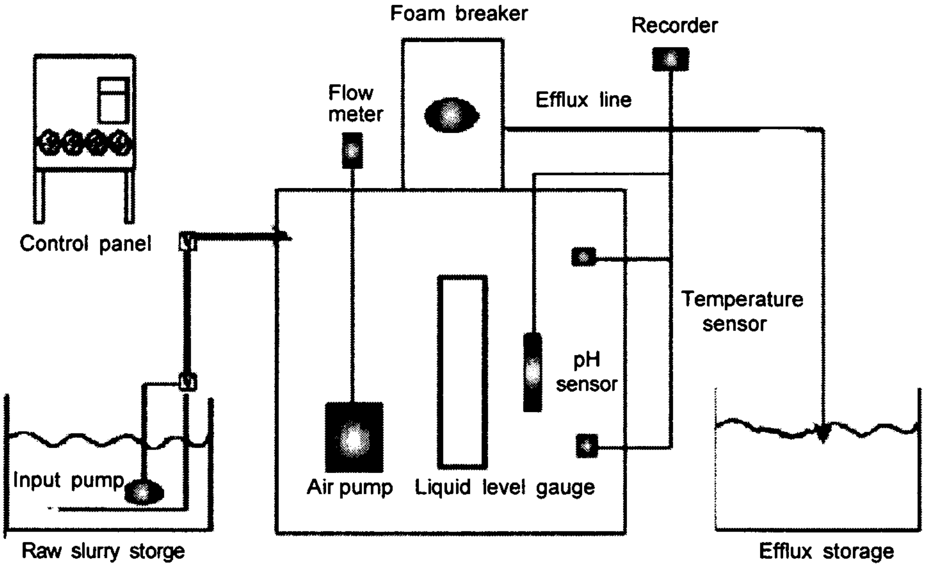

Fig. 1. Diagram of the thermophilic aerobic slurry composting system.

conditions of the reactor in field scale unit, the number of air pumps and foam breakers was varied. Treat-A consisted of 2 air pumps (aeration rate ; 120 m^3 air/hr) and 2 foam breakers: Treat-B, 3 air pumps (aeration rate ; 180 m^3 air/hr) and 3 foam breakers; and Treat-C, 3 air pumps (180 m^3 air/hr) and 4 foam breakers. The influent flow rate in pilot scale unit was also changed; 50 ℓ every 2 hrs, 50 ℓ every 3 hrs, 40 ℓ every 2 hrs, and 60 ℓ every 4 hrs, in a continuous mode, to find the most efficient reduction conditions. The liquid levels, temperatures and evaporation rates were measured for each flow rate (Table 1).

The temperature was continuously recorded and the slurry volume was also measured using an acryl plate. The reduction in the slurry volume was recorded for 5~18 hours after the bubble formation was disappeared to recognize the completion of the reaction. The evaporation rate was measured by the discrepancy between the input and output swine manure slurry quantities, using the method developed by Lee and Lee (1998). Physicochemical characteristics of pH, total nitrogen (T-N), ammonium nitrogen (NH_4-N), total phosphorus (T-P), soluble phosphorus (PO_4-P), total solid (TS), and volatile solid (VS) were analyzed by ion chromatography (DX-120, Verian Inc.), and Cl$^-$, K, Na$^+$, SO_4^{2-} and Mg^{+2} were analyzed by ICP-MS [ICP-AES (Liberty 220), Verian Inc.] (American Public Health Association et al., 1989).

Table 1. Operational conditions of the field and pilot scale experimental units

Field scale (Experiment 1)

Parameters	Treatment A	Treatment B	Treatment C
Number of air pumps (Aeration volume : 60 m^3/hr) (EA)	2 (aeration volume : 120 m^3/hr)	3 (aeration volume : 180 m^3/hr)	3 (aeration volume : 180 m^3/hr)
Number of foam breaker(1,200rpm/min) EA)	2	3	4
Total Input volume	7.8 m^3 (2.1 m^3/day)	15.3 m^3 (3.1 m^3/day)	43.2 m^3 (5.1 m^3/day)
Operation time	99 hr	134 hr	204 hr
Reactor volume (working volume) TS range in Feed and Working water level	52m^3 (21m^3) 2.8 ~ 8.4 %, 80 ~ 100 cm		

Pilot-scale (Experiment 2)

Parameters	T- 1	T- 2	T- 3	T- 4
Influx volume (Total influx volume/day)	50 ℓ /2hr (600 ℓ /d)	50 ℓ /3hr (400 ℓ /d)	40 ℓ /2hr (480 ℓ /d)	60 ℓ /4hr (360 ℓ /d)
Reactor volume (working volume) TS range in feed Number of air pump Number of foam breaker (1,200 rpm/min) Working liquid level and output volume	1.1 m^3 (0.6 m^3) 2.0 ~ 3.0 % 1 1 30~50cm, 60% of Input volume			

RESULTS

Experiment 1

The effects of the aeration and the numbers of foam breakers on the liquid level in the reactor are shown in Fig. 2. The reductions of the liquid levels in the reactors were 50~100 cm, 40~90 cm, and 40~70 cm in Treats A, B and C, respectively. The running times per treatment were 99, 134, and 204 hrs for Treat A, B and C, respectively. The results indicated that Treat-C was the most stable in terms of its operation. The radical liquid level change of 20~30 cm in each treatment was due to the injection of new slurry.

The level of aeration and the numbers of foam breakers in the operation per treatment were as follows: Treat-A (aeration rate ; 120 m^3 air/hr using 2 air pumps with 2 foam breakers), Treat-B (aeration rate ; 180 m^3 air/hr using 3 air pumps with 3 foam breakers) and Treat-C (aeration rate ; 180 m^3 air/hr using 3 air pumps with 4 foam breakers). The slurry input for all treatments was 5 m^3/day. The final water level was measured for each treatment after 20 hours of operation. Minor differences in the water level change seemed to be normal.

The effects of the aeration and the numbers of foam breakers on the temperature change are shown in Fig. 3. The temperature ranges per treatment were 31~64℃, 29~52℃ and 45~54℃ for Treat-A, B and C, respectively. Likewise, Treat-A, B and C showed temperature differences before and after injection, of 33, 23 and 9℃, respectively. Thus, in order to secure a stable reactor operation, the changes in the liquid level and temperature should be kept to a minimum. To determine the effects of the external temperature on the internal temperature of the reactor, a reactor was operated under the Treat-C conditions for 8 months (from January to August, 2002).

The numbers of air pumps and foam

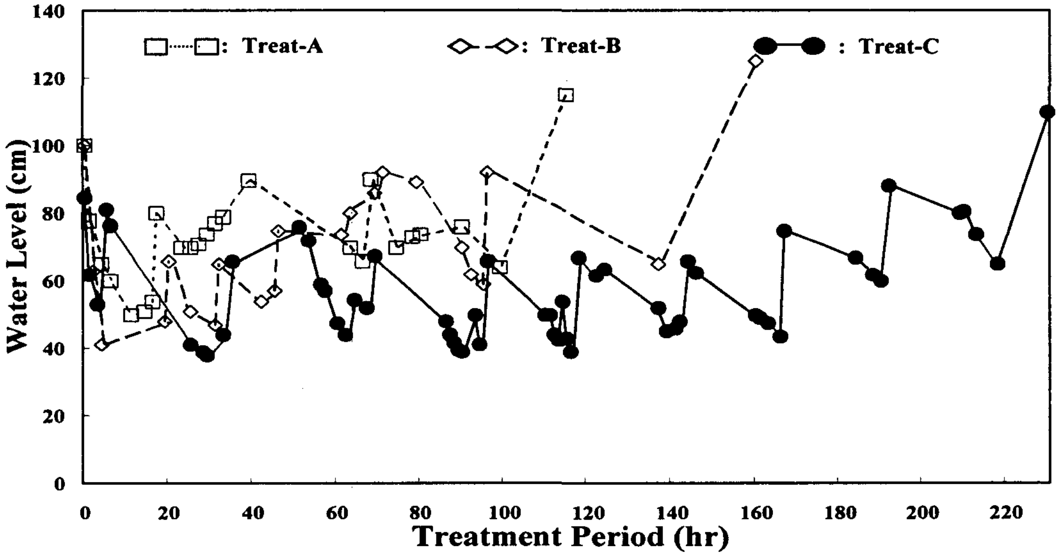

Fig. 2. Effects of aeration and the numbers of foam breakers in the TAO reactor on the water level changes.

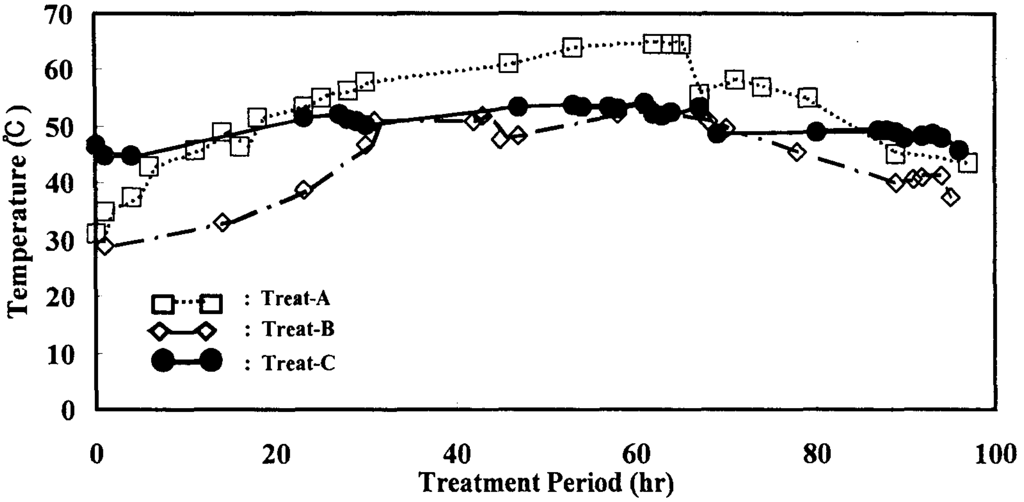

Fig. 3. Effects of the level of aeration and the numbers of foam breakers in the TAO reactor on the internal reactor temperature.

breakers operated per treatment were as follows : Treat-A(aeration rate ; 120 m^3 air/hr using 2 air pumps, with 2 foam breakers), Treat-B (aeration rate ; 180 m^3 air/hr using 3 air pumps, with 3 foam breakers) and Treat-C (aeration rate ; 180 m^3 air/hr using 3 air pumps, with 4 foam breakers). The reactors were stabilized by 24 hours of operation prior to the experiments. A temperature change of up to 50 ℃ was observed inside the reactors.

The resulting average internal temperature of the reactor over the 8 months is shown in Fig. 4. Even in January and February, the average internal temperature of the reactor was above

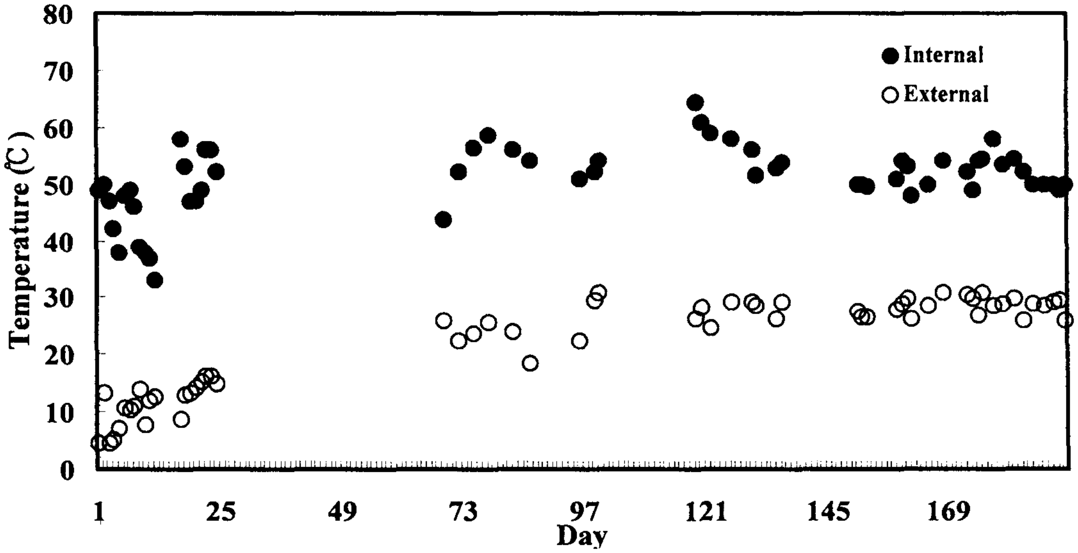

Fig. 4. Change in the internal and external temperature of the reactor under Treat-C conditions during 8 months.

40℃ when the external temperature was below 0℃. The results thus show that the effect of the external temperature was insignificant for the internal temperature of the reactor.

The output and evaporation rates per treatment, and per unit area are shown in Fig. 5. The biodegradation and evaporation rate per treatment and per unit area of Treat-A, B and C were 43 and 57%, 48 and 52%, and 49 and 51%, respectively. Therefore, the difference seemed not significant. Nevertheless, there were significant differences in the reduction volumes per unit area per treatment resulting in 55.5 ℓ/m^2/day, 75.0 ℓ/m^2/day and 120.0 ℓ/m^2/day, respectively for Treat-A, B and C.

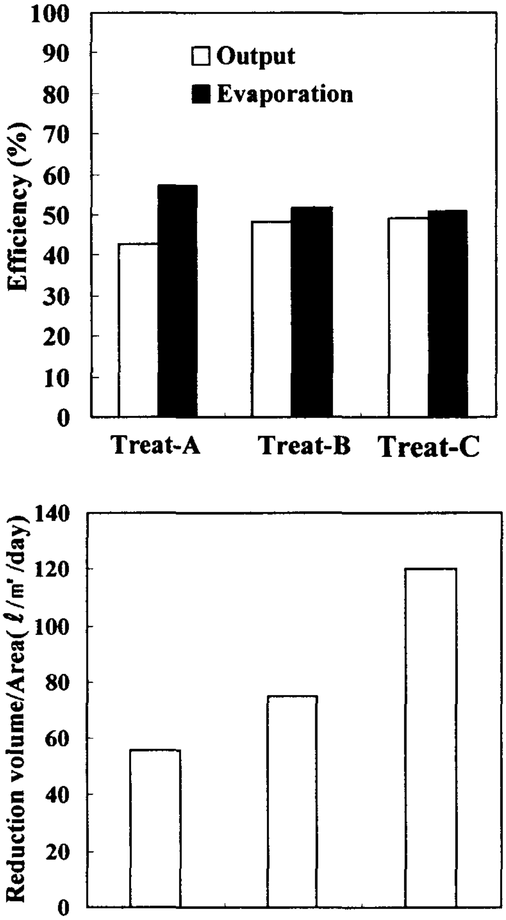

Fig. 5. Comparison of the residual sludge volumes, evaporation and reduction volume/areas in experiment 1 (Treat A; 120 m^3 air/hr with 2 foam breakers, Treat B; 180 m^3 air/hr with 3 foam breakers, Treat C; 180 m^3 air/hr with 4 foam breakers).

The significant difference of reduction volumes (ℓ/m^2.day) between T-A, T-B and T-C was results from the difference of the total input volume and operation time in each treatment.

Experiment 2

The effects of the amount of the injected slurry on temperature change for 24 hours are shown in Fig. 6. The average temperatures per treatment were 44.8, 46.7, 50.8 and 59.5℃ respectively for T-1, 2, 3, and 4. The results indicated that T-4 made the highest average temperature. Compared to Treat-C, T-4 was shown a higher average temperature by 10℃. Likewise, the other three treatments made higher temperatures compared to the treatments in Experiment 1. Whereas the internal temperature decrease due to the injection of the raw specimen was about 10℃ in Experiment 1, but only about 2~3℃ in Experiment 2. These results show that the internal temperature was more stably maintained in the reactor during Experiment 2.

The amount of slurry injected per hour, per treatment were as follows: Treatment 1 ; 50ℓ/2hrs, Treatment 2 ; 50ℓ/3hrs, Treatment 3 ; 40ℓ/2hrs, and Treatment 4 ; 60ℓ/4hrs. The results were based on data gathered 24 hours after completion of the experiment.

Fig. 7 shows the discharge, evaporation rate, and evaporation per unit area, according to the

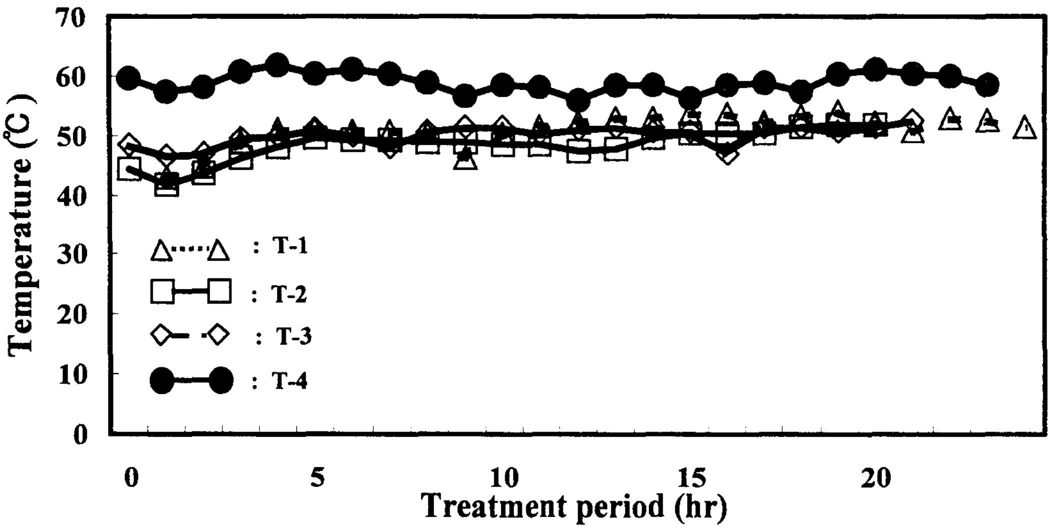

Fig. 6. Effect of slurry injection rate on internal reactor temperature in pilot scale reactor in experiment 2.

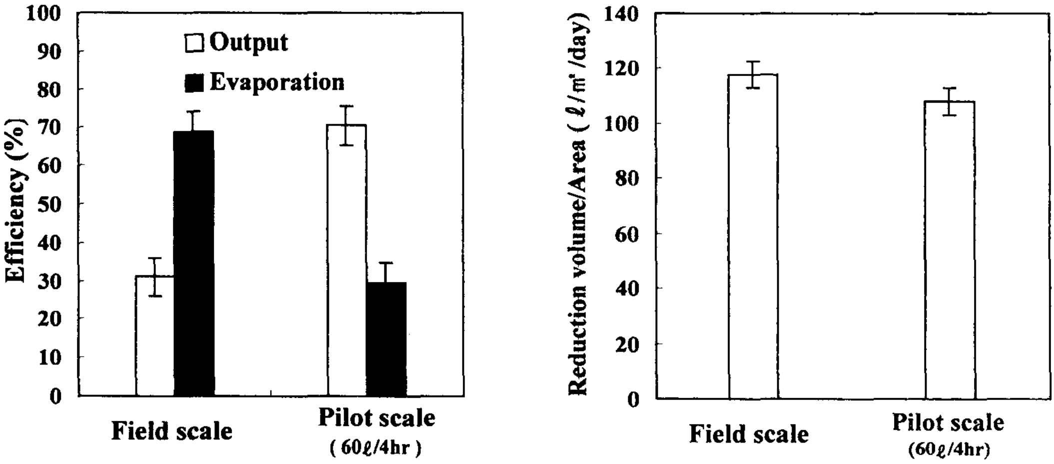

Fig. 7. Comparison of output, evaporation and reduction volume/area at field and pilot scale experimental unit Total operation and each interval time of the field (Treat C, 180 m^3 air/hr with 4 foam breakers) and pilot (T-4) units were 389 and 43hr, and 60 and 4hr, respectively.

amount of slurry injected, in order to compare the process efficiency of Treat-C with T-4. Treat-C was operated nine times successively. The total input, discharge and evaporation were 59.1, 15.3 and 41.6 m^3, respectively. Conversely, T-4 was operated 14 times successively in semi cotinuous mode. The total input, discharge and evaporation were 840, 515 and 264 ℓ, respectively. The total operation time was 75 hours. The evaporation rate of Treat-C was higher than that of T-4 (70 and 31%, respectively). Also, the reduction volume per unit area of Treat-C was very similar to that of T-4 (118 and 108 ℓ/m^2/day respectively).

This was probably due to the higher average temperature of T-4 compared to Treat-C.

DISCUSSION

The average internal reactor temperature was maintained above 40℃, which was consistent with the conditions reported by Hong, et al., (1998), i.e., and that the process temperature should be greater than 40℃ for liquid composting. For the pilot scale, a temperature of more than 50℃ should be maintained. The temperature is required to destroy the harmful microbes and viruses contained within excretions, thus making the production of a sanitary and stable fertilizer possible (Heinonen, et al. 1998; Phae, et al. 1999; Timothy, et al., 2000). When the total power and four moisture evaporation equipments were operated for a month, the evaporation rate became 118 ℓ/m^2/day, thus reducing the level of excretions by about 70%. In 1998, Chung, et al., (1998) estimated the amount of pig excretions in Korea at 1.5×10^7 tons/year. The TAO system may therefore reduce the amount of excretions to only 4.5×10^6 tons/year. In 1995, Lee et. al. (1995a), reported that the solid content of the excretion should exceed 4.5% in order to properly operate the TAO system. This study results was consistent with that of Lee, et al, with an excretions solid content of 5~7%. The results were also similar to the solid content discharged from a general pig-raising farmhouse described by Lee and Lee(1996). It is thus possible to process excretions without separating them from liquid. Consequently, neither a solid-liquid separation moisture regulator, which is used to process excretions after their separation, nor a facility to purify excretions, are needed, thus minimizing the costs of the excretion treatment process.

The application of animal excretions to the soil minimizes pollution and provides mineral nutrients to the soil, thus decreasing the use of chemical fertilizers and increasing the soils organic matter content (Lee, et al., 1995b; Long and Gracey, 1990; Wilkinson, 1979).

Efflux processed by a reactor contains 4,862 mg/ℓ total nitrogen, 30% of which is ammonia nitrogen (1,364 mg/ℓ). Efflux is therefore harmless to crops when sprayed on the soil (Ministry of Agriculture and Forestry, 1997). Moreover, the National Institute of Agricultural Science and Technology reported no adverse effects from the spraying efflux on soil, since the crop yields from soils sprayed with treatment water containing pig slurry were similar to those from soils sprayed with chemical fertilizer.

Table 2. The chemical composition of piggery slurry and efflux

(unit : mg/L)

Item	Piggery slurry	Efflux
pH	6.72	8.46
TS(%)	5.1	5.4
VS(%)	72.4	65.4
Total Nitrogen	4,892	4,862
NO_2^-	47	14
NO_3^-	19	16.6
NH_4^+	1,922	1,364
TP	837	1,397
PO_4^-	778	526
Cl^-	1,256	1,497
Ca^{2+}	897	2,137
Na^+	638	757
Mg^{2+}	298	517

CONCLUSIONS

The optimal operating condition and process efficiency were determined by investigating the liquid content, temperature and evaporation rate using a in field and a pilot scale (semi-continuous) TAO system. The results indicated that the optimal operating condition of the field and pilot scale required 3 air pumps and 4 foam breakers (Treat C) with a fed of 60 ℓ every 4 hours (Treat 4). The slurry reduction and evaporation rates were 70 and 31%, respectively. The difference of the evaporation rate and reduction volume between T-C (Exp.1) and T-4 (Exp.2) also due to the relative difference of the input volume to the working volume everyday (T-C:25%, T-4:60%). The average temperature of the reactors for Treat C and T-4 were 50 and 59.9℃, respectively. Therefore, it is possible to reduce the moisture content and process liquid pig compost in a sanitary manner. The results of this study may also be applied to the processing other animal manures, as well as to the treatment of pig slurry and the processing of highly dense organic waste-waters.

적 요

현장규모 (8.6×2.5×2.4 m) 및 파이롯트규모 (1.39×0.89×0.89 m)의 고온호기산화장치를 이용하여 공기투입량 및 처리온도에 따른 양돈분뇨의 감량화 효율을 검토하였다. 현장규모에서 공기투입장치, 거품제거장치의 설치조건이 양돈슬러리 증발량과 처리온도에 모두 영향을 미치고 있음을 알 수 있었다.

현장규모 연구는 3가지의 처리방법 (처리A: 공기공급량 120m^3/h, 수중펌프 2대, 소포장치 2대; 처리 B: 공기공급량 180m^3/h, 수중펌프 3대, 소포장치 3대; 처리C: 공기공급량 180 m^3/h, 수중펌프 3대, 소포장치 4대)으로 실행되었다. 1일 5m^3 양돈슬러리를 동일하게 투입하면서 얻어진 연구결과, 수위변화, 온도변화 및 증발량은 각각 처리A: 50~100cm, 31~64℃, 55L/m^2 · day, 처리B: 40~90cm, 29~52℃, 75L/m^2 · day, 처리C: 40~70cm, 45~54℃, 120L/m^2 · day이었다.

한편 파이롯트 규모 연구는 반 연속식으로 양돈분뇨를 투입하면서 매일 투입량을 처리1: 50L/2h, 처리2: 50L/3h, 처리3: 40L/3h, 처리4: 60L/4h으로 하여 최대 슬러리 감량조건을 도출하기 위해 수행하였다.

(**핵심단어** : 증발량, 슬러리, 양돈분뇨, 온도, 고온호기산화장치)

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