Field Application of a Continuously Aerated Bio- Reactor (CABR) for the Treatment of Swine Wastewater

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양돈분뇨처리에 있어서 연속폭기배양조(CABR)의 현장적용연구

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요 약

본 연구는 최근 개발된 광합성세균(*Rhodopseudomonas capsulata*)을 이용한 연속적 폭기식 생물반응조(이하 CABR)를 이용한 무희석 양돈 분뇨의 처리 결과를 보고하고 있다. CABR를 이용하여 24시간 동안 양돈 분뇨를 폭기 처리한 결과 유입량의 40%가 증발되었고, 유입분뇨의 전체 BOD, COD중 87%, 32%가 각각 제거되었으며, 전질소(T-N), 전인(T-P)은 각각 110%, 112%로 증가되었다. CABR 배출액의 질소 형태를 분석한 결과 암모니아성 질소(NH_4-N) 농도는 저하된 반면, 유기태 질소(Org-N)농도는 증가하였다. 양돈분뇨의 주요 BOD원이며 악취의 주요물질인 저급지방산은 CABR의 처리결과 거의 제거 되었다. 한편 CABR 배출액의 유기액비로서의 이용성을 검토하였다.

CABR 배출액은 식물성장에 필요한 질소, 인산, 칼리의 함량이 비교적 균형있게 포함되어 있으며, 특히 질소의 86%는 유기태질소(Org-N)로 되어 있어 완효성 비료로서의 이용 가능성이 시사되었다. 또한 중금속의 함량도 낮아 위해성의 문제는 없는 것으로 밝혀졌다. 이탈리안 라이그라스(목초)의 토경재배 실험결과 일반 화학비료에 비해 생육량이 증가되었으며, 특히 질산태질소(NO_3-N)의 작물내 함유량이 매우 낮았다.

이러한 결과는 CABR 배출액이 농작물 생산에 매우 적합한 유기액비로서 이용할 수 있음을 시사하고 있다.

(핵심어 : 양돈분뇨, CABR, 배출액, 광합성세균, 이탈리안 라이그라스, NO_3-N)

SUMMARY

A wastewater purifying system using phototrophic bacterium, *Rhodopseudomonas capsulata*, is currently in operation in several countries, One of them, is a continuously aerated bioreactor(CABR) system, which treats concentrated swine wastewater using small amounts of phototrophic bacteria as additive bacterial seeding. Using this plant, total biochemical oxygen demand was decreased to 13 %, and most of volatile fatty acids were removed. About 40% of the wastewater(Influx) was evaporated during aerobic digestion for 24h, and

60% of that erupted in a deodorized foam(Efflux). The efflux had enough nutrients, N, P and K for growing plant, as well as organic matters. When the efflux was applied to Italian ryegrass with high dose, fresh shoot and root weights were significantly greater, and NO_3-N contents of the dried shoot were lower than those of control plant (CDU).

These results indicate that the CABR plant is useful for reduction and deodorization of swine wastewater and the efflux from CABR can be used for crop production as an organic fertilizer.

(**Key words**: Swine Wastewater, CABR, Efflux, Phototrophic Bacterium, Italian Ryegrass, NO_3-N)

INTRODUCTION

One of the most urgent problem in the practices of intensive livestock farming today is disposing of the animal wastewater in a manner that is environmentally acceptable and economically feasible. In the past animal wastewater were used as a manure in the recycling system of agriculture. However, swine wastewater can not be allowed to be used as a manure currently, since it generates extremly high concentration of malodorants and consequently becomes a source of pollution. In the last two decades, many efforts have been made to reduce malodor, BOD, COD, nitrogen and phosphorous of the swine wastewater(Ohta and Ikeda[14]; Kameoka et al.[5]; Kakiichi et al.[6]).

An activated sludge system or a lagooning system, although, could be used to treat concentrated organic wastewater, such a system would be too expensive for pig breeding farms in developing countries(Yang and Koba[17]). Consequently, the development of a more economic wastewater treatment system has been needed. The alternative purification method is thermophilic aerobic liquid composting system without separation into sewage and sludge, which is characterized as an aerobic treatment process leading to elevated temperature and applied to concentrated organic wastewater such as a manure (Terwillleger and Crauer[15]). Thermophilic aerobic composting, even though, has the following general merits : (1) it converts animal wastewater to stabilized organic materials not to hazardous to plant growth, (2) it facilities the secondary treatment of the wastewater, if necessary, by the reduction of water content and malodor, (3) it markedly shortens the operation time and scale need for the treatment of wastewater, this imposes an additional stress upon the process in terms of foaming with solids and severe clogging of the aerator in the aeration tank(Terwilleger and Crauer[15]).

R. capsulata is a purple non-sulfur bacterium widely distributed in the environment, and plays on important role in the preservation of water in its natural habitat(Hirotani et al.[4]). This bacterium is utilized in wastewater management site (Kobayashi[7,8,9,10]) in several countries.

In recent years, a modified thermophilic liquid composting system, a continuously aerated bio-reactor(CABR) system using phototrophic bacterium, *R. capsulata,* has been developed to solve these problems in the swine farms and successfully applied for the treatment of the fresh swine wastewater from pens. In this paper the operational characteristics of the CABR and the feasibility of the swine wastewater treated by a CABR as an organic fertilizer are described.

MATERIALS AND METHOD

1. Equipment And Operation Procedure

A 32m^3 phototrophic CABR wastewater

treatment plant was investigated. This plant had overall dimensions of 4.2m in length, 3.8m in width and 2.0m in depth, and is in operation for the treatment of swine wastewater (Fig. 1).

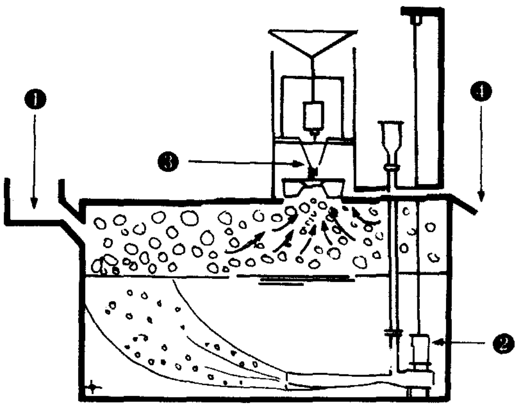

Fig. 1. Scheme of continuously aerated bio-reactor(CABR)

1. inlet(Influx)	2. air compressor
3. foam cutter	4. outlet(Efflux)

Every day about 3m^3 of the swine wastewater was flushed into the tank through an inlet as an influx. The amount of 3m^3 wastewater corresponded to that dropped out daily from pens with 500 swines. At the same time 30~100ml of *R. capsulata* suspension(10^{12}cell/ml) was added to the tank. About 15m^3 the swine wastewater remained inside the tank. Air was drawn continuously into the CABR tank through a mechanical aerator(pump) fixed to the bottom of the tank at the rate of 65m^3/h. During the aeration, the wastewater in the tank foamed extremely. Consequently, it was defoamed by a bubble cutter installed at the top of the tank, and the resulting liquefied sludge was collected for 24h in a plastic bottle through outlet as an efflux. The collected influx and efflux were kept in an insulated cooler and used for the experiments promptly upon return to the laboratory about 8h after sampling.

2. Organisms

A phototrophic bacterium(PTB), *R. capsulata* was used. PTB was cultured in an aerobic condition under illumination. After culture, a concentrate of this bacterium was obtained by centrifugation.

3. Measurement of microbial cell number

Aerobic heterotrophic bacteria were enumerated by the plate method using 1/10 porcine feces agar medium which contained of procine feces and the pH adjusted at 8.2 ; 0.1ml portions of appropriate dilutions of samples were spread over the agar surface and incubated at 30℃ and 50℃ for 7~10 days before counting mesophilic and thermophilic bacteria, respectively. For enumerating phototrophic bacteria, most probable number(MPN) method modified(Hiraishi and Kitamura[3]) was used. Samples were also tested for the enumeration of total coliform as enteric indicator microorganism by MPN method on the BGLB medium.

4. Nutrient stock solution

Based on the element composition of the efflux (Table 3), nutrient solution composed of chemical fertilizer was prepared as references ; the solution with crotonylidene diurea as a slow-releasing nitrogen fertilizer was designated as "CDU", The chemical composition and element composition of the stock solutions are shown in Table 5 and 6.

5. Plant culture

Aliquots of the efflux and the stock solutions of CDU were pipetted and mixed with the soil (Akadama-tsuchi). The pH of the solutions was adjusted to 6.5 before mixing. Then the soils mixed with the efflux and CDU at 100, 200, 400, 800 and 1,600mg-N/kg soil were prepared (designated as N-100, N-200, N-400, N-800 and N-1,600, respectively). The final element compositions are shown in Table 7. These soils (each 1kg) were placed in 1 ℓ plastic pot and used for soil culture of Italian ryegrass plants. Italian ryegrass seeds(0.3g) were sown in each pot containing 1kg of the soil supplemented with nutrients as described above. All shoots of the plants were harvested(30 days culture) and subjected to analysis. During the culture no topdressing was supplied.

6. Chemical analysis

The chemical oxygen demand(COD_{Mn}), and biochemical oxygen demand(BOD_5) were assayed according to the Japanese Industrial Standard(JIS) K-0102(1985)

The nitrogen(N) content was measured by Kjeldahl digestion followed by steam distillation and indophenol blue method ; phosphorous(P) was measured colorimetrically with metavanadate reagent after Kjeldahl digestion. Potassium(K), calcium(Ca) and magnesium(Mg) were measured by the method of atomic absorption spectrophotometry after nitric-perchloric acid digestion. The NO_3-N contents were calculated from a difference between nitrogen contents by salycylic-sulfuric acid digestion and Kjeldahl digestion. The dry weight of samples were measured until constant weight was obtained after drying at 105 ℃.

For the measurement of short chain fatty acids, 10ml of the influx(swine wastewater) and the efflux was acidified with 2ml of 1 N HCl. Fatty acids in the acidified sample(12ml) was immediately extracted with 10ml of diethylether. After storing at −20℃ for 4h, 5μl of the diethylether layer was subjected to GC analysis. GC was equipped with FID and a column(3mm i.d. × 2m) packed with 10% polyethylene glycol 6000 on Shimarite TPA 60/80. Other conditions were as follows : carrier gas, N_2(30ml/min) ; column temperature, 150℃ ; injector and detecter temperature, 200℃. Each compound was identified by comparision of the retention time with those of authentic specimens. Isocaproic acid was added to the sample as an internal standard immediately before acidification, since this fatty acid was not detected appreciably in the swine wastewater. The amounts of fatty acids were calculated from peak areas.

RESULTS & DISCUSSION

1. Apparent efficiency

Table 1 shows the total volume, dry weight, pH, color and temperature of the influx, at the beginning and at the end (after 24h) of the treatment and efflux foam of the CABR. Within 2h of the inoculation of PTB to swine wastewater, the temperature of the wastewater rapidly increased from 35℃ to 50℃ and was maintained high for one day. During this process, the pH of the solution gradually increased to 8.2. The outflow of the efflux foam gradually decreased and the color of the foam was black. Under the field condition, 40% volume of the influx evaporated and the malodorous smell completely disappeared finally.

2. Chemical properties of the efflux

Table 2 summarizes chemical properties of the influx and the efflux of the CABR. BOD and COD decreased to 13 and 68%, respectively, while the total nitrogen and phosphorous did not. This means organic materials involved in the fresh swine wastewater were degraded during the treatment. An organic form of nitrogen(Kjeldahl nitrogen minus ammonium nitrogen) was predominant in the efflux, according for more than 80% of total nitrogen, ammonium nitrogen 13% and nitrate nitrogen 3%. When we compared the nitrogen composition of the influx and the efflux, ammonium nitrogen had decreased and organic nitrogen had increased after the treatment. This suggests that ammonium nitrogen may be introduced into the microbial cells. The elemental composition of the efflux is given in Table 3. The efflux contained most of elements essential for plants. Cadmium, a heavy metal toxic to plant growth and human health, did not exceed the concentration regulated by law. These findings indicate that the efflux could be used as an organic fertilizer, a compost.

Table 1. Parameters of CABR

	Influx	Efflux	Total Efflux / Total Influx × 100
T-volume (m^3)	2.8	1.8	64
Feces (m^3)	0.3	–	–
Urine (m^3)	2.4	–	–
Dry weight (kg)	168	127	76
Water content (kg)	2,622	1,643	63
Ash (kg)	35	24	69
pH	7.0	8.2	–
Temperature (℃)	25	40 ~ 50	–
Outflow rate (l/h)	–	50 ~ 240	–
Color	yellow-brown	brown-dark	–

Table 2. Chemical properties of Influx and efflux

	Influx	Efflux	Total Efflux / Total Influx × 100
	(mg/l)	(mg/l)	
BOD_5	55,687	11,500	13
COD_{Mn}	5,210	5,675	68
Kjel-N	1,937	3,410	110
NH_4-N	728	457	39
NO_3-N	53	105	123
P	1,250	2,250	113
Acetic acid	4,687	171	2
Propionic acid	1,187	30	2
Butyric acid	978	11	1
Valeric acid	569	N.D.*	0

* N.D. : Not detected.

Table 3. Element composition of efflux

Element	Content (mg/l)
T-N	3,515
NH_4-N	457
NO_3-N	105
Org-N	2,953
T-P	1,878
K	1,596
Ca	2,742
Mg	740
Na	384
Fe	234
Zn	50
Mn	28
Cu	19
Cd	0.002

In addition, short chain length fatty acids such as acetic, propionic and butyric acids decreased dramatically as a result of the treatment(Table 2). These fatty acids were one of the major source of malodor evolved from the swine wastewater (Bourque et al.[1]). Thus the CABR was also efficient for deodorization.

3. Microbial properties of the efflux.

Table 4 shows microbial distribution in the influx and the efflux of the CABR. After the swine wastewater was introduced into the CABR tank with phototrophic bacteria, the temperature in the tank rose gradually and reached 50℃ as described above. The major class of micro-organisms in the influx was mesophilic bacteria. However, thermophilic bacteria in the efflux increased by more than 20 times that of the influx under this thermophilic condition while the mesophilic bacteria remainded rather constant. Filamentous bacteria were not detected in the efflux. Two types of bacteria, thermophilic and mesophilic, were, thus, major classes in the efflux. Phototrophic bacteria increased by 8 times, whereas the cell number of phototrophic bacteria was still far less than that of the thermophilic and mesophilic bacteria. On the other hand, 1.2×10^8 cell/ml of thermophilic bacteria and 2.1×10^7 cell/ml of mesophilic bacteria existed in the CABR tank at the end of the treatment. Therefore, degradation of organic materials may be carried out by thermophilic and mesophilic bacteria. However, it appears that phototrophic bacteria contributed to the deodorization of swine wastewater since the absence of phototrophic bacteria from the CABR did not produce foams nor reduce generation and emission of the malodorants(Lee[11]). Coliform bacteria, which were enteric indicator microorganisms, decreased in the efflux, and fungi were not detected. A CABR is, thus, efficient to repress the growth of coliform bacteria and fungi and consequently the efflux seems to be safe for farmers and also plant growth in terms of microflora when it is applied to agricultural lands.

Table 4. Microbial properties of influx and efflux

Microorganism	Number of microorganism (cell/ml)	
	Influx	Efflux
Mesophilic bacteria	3.4×10^7	6.5×10^7
Thermophilic bacteria	8.5×10^5	2.0×10^7
Phototrophic bacteria	1.1×10^2	9.0×10^2
Coliform bactera	1.6×10^3	3.5×10^2
Fungi	6	N.D

4. Growth and Nitrogen Contents of Italian ryegrass

Fig. 2 shows the effect of the efflux and CDU on the growth of Italian ryegrass plants on fresh weight base in soil culture. Growth was similar in N-100, N-200, N-400 and N-800 between the plants cultured with the efflux and CDU, while the growth of the plants cultured with the efflux in N-1,600 was superior to that with CDU. Therefore, growth of Italian ryegrass cultured with the efflux was comparable with that of CDU in N-100, N-200, N-400 and N-800. However, when large amounts of the fertilizers(N-1,600) were applied to the soil, the growth with CDU was reduced but the growth with the efflux was still enhanced.

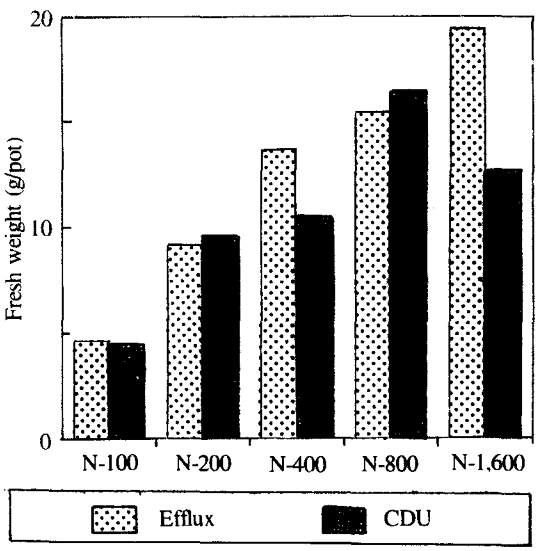

Fig. 2. Effect of efflux and CDU on the fresh weight of Italian ryegrass shoots

The total nitrogen contents of the shoots of the plants cultured with the efflux were lower than those with CDU in all plots(Fig. 3). It is desirable that NO_3-N content is less than 10mg/g dry weight in shoots for animal fodder(Lewis[12]). Contents of NO_3-N increased with increasing application of CDU ; more than 10mg/g dry weight in N-400, N-800 and N-1,600(Fig. 4). However, contents of NO_3-N in shoots cultured with the efflux were lower than 10mg/g dry weight.

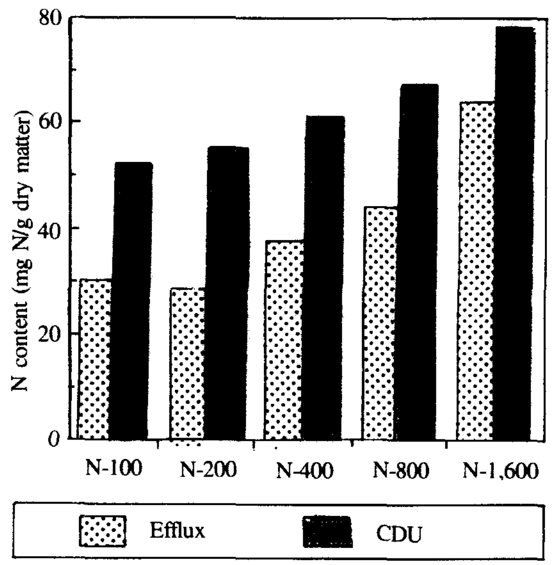

Fig. 3. Effect of efflux and CDU on N contents of Italian ryegrass shoots

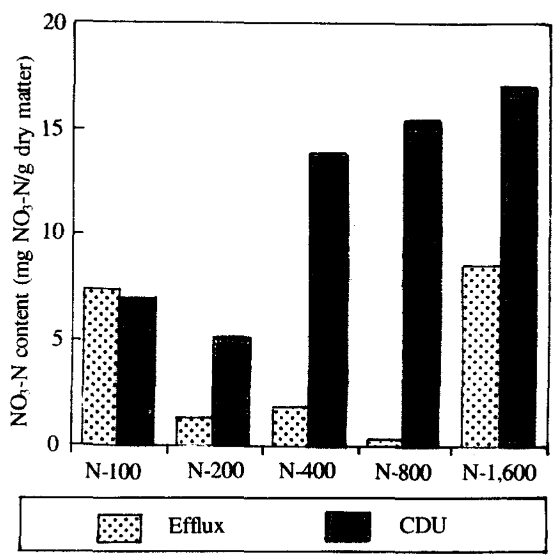

Fig. 4. Effect of efflux and CDU on NO_3-N contents of Italian ryegrass shoots

Table 5. Chemical compositions of stock culture solutions for plants

Efflux		CDU	
Component	Content (mg/l)	Component	Content (mg/l)
NH_4-N	457	$(NH_4)_2SO_4$	2,155
NO_3-N	105	KNO_3	757
Organic-N	2,953	CDU mixed*	6,464
T-P	1,878	Na_2HPO_4	6,234
K	1,596	KCl	1,001
Ca	2,742	$Ca(NO_3)_2 4H_2O$	16,178
Mg	740	$MgSO_4 7H_2O$	7,552

* CDU mixed fertilizer composed of N (8% from CDU and 8% from$(NH_4)_2HPO_4$), P (8% from $(NH_4)_2HPO_4$) and K (12% from K_2SO_4).

Table 6. Element compositions of stock culture solutions for plants

Element	Content(mg/l)		Element	Content(mg/l)	
	Efflux	CDU		Efflux	CDU
T-N	3,515	3,515	P	1,878	1,878
NH_4-N	457	974	K	1,596	1,592
NO_3-N	105	2,024	Ca	2,742	2,742
Organic-N	2,953	517	Mg	745	745

Table 7. Composition of soil culture solution for Italian ryegrass

Culture Solution	Element	Content (mg/kg)				
		N-100	N-200	N-400	N-800	N-1600
Efflux	T-N	100	200	404	808	1,616.9
	NH_4-N	13.0	26.0	52.5	105.1	210.2
	NO_3-N	3.0	6.0	12.0	24.1	48.3
	Org-N	84.0	168.0	339.5	679.2	1,358.3
CDU	T-N	100	200	404	808	1,616.9
	NH_4-N	27.8	55.5	112.0	224.0	448.0
	NO_3-N	57.6	115.1	232.6	465.5	931.0
	Org-N	14.6	29.4	59.4	118.9	237.8
	P	53.5	107.0	216.0	431.9	863.9
	K	45.5	91.0	183.5	367.1	734.1
	Ca	78.1	156.2	315.3	630.7	1,261.3
	Mg	21.2	42.5	85.7	171.4	342.7

Micronutrients of Kimura's B solution were supplied to CDU; Mn(0.04mg/l), B(0.01mg/l), Mo(0.001mg/l), Zn(0.001mg/l), Cu(0.001mg/l) and Fe(5.0mg/l).

This may be due to an organic form of nitrogen in the efflux ; organic nitrogen accounted for more than 80% in the efflux. This was supported by the fact that nitrogen contents in the shoot cultured with efflux was lower than those with CDU, although the contents increased gradually. About 80% of the nitrogen was also inorganic in CDU, although crotonylidene diurea, a slow-releasing nitrogen fertilizer, was involved. Thus, it appears that plants take up inorganic nitrogen quickly in large amounts under the soil culture with CDU. In contrast, organic nitrogen compounds in the efflux may degrade gradually and be taken up by plants slowly, which results in better growth. It remains to be solved what types of organic nitrogen compounds are involved in the efflux. It is noted that the application of the efflux enhanced root growth and the development of root hairs (data not shown).

Accumulation of NO_3-N in pasture plants has been reported to be harmful to animal health (Lewis[12]). Application of the efflux maintained a low level of NO_3-N in plants compared with CDU.

The findings presented here suggest that the efflux of the swine wastewater treated in a CABR with *R. capsulata* can be utilized as an organic fertilizer in agriculture. However, further careful evaluation will be required when the efflux is applied to the soil continuously in large amounts.

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