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A PRACTICAL TREATMENT OF SWINE LIQUID MANURE FOR LAND APPLICATION USING CHARCOAL, SHELL, AND ZEOLITE IN AN AERATED REACTOR

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ABSTRACT

We focused on a practical treatment of animal liquid manure for land application using some materials in an aerated reactor. After solid-liquid separation of animal manure in a barn, liquid manure is moved to three to five tanks sequentially. At each tank a reactor is suspended and aerated with air pump. The reactor consists of pumice, granite, and soil pellet, not only promoting biological digestion of the manure but also providing some minerals in it. The soil pellet is sometimes alternated by the powdery soil, spread at the bottom of the tanks. The aerated reactor system is called "BMW", meaning bacteria, mineral, and wastewater. After qualified for three week to a month in the sequential tanks, the wastewater, low in organic materials and rich in minerals, is used for plant cultivation as an activated fertilizer.

In this study, we investigated the wastewater quality of the BMW plant installed at a large-scale swine farm as well as the modified BMW plant built at a small-scale swine farm. The BMW plant used the materials of soil, granite, and pumice in an aerated reactor. The modified BMW plant used charcoal, shell, and zeolite and therefore was renamed as the CSZ plant. A land application of the treated wastewater from the BMW plant was examined to yam potato production. In addition, at lab scale model plants we investigated the purification and mineral dissolution mechanism of the materials used in the BMW plant, the CSZ plant, and the Non-Material plant that used nothing in the aerated reactor.

Using the additional 5th tank and the scallop shell in the aerated reactors, the BMW plant kept a preferable condition of pH in the 4th and 5th tank and increased a conversion rate of NH_4-N to NO_3-N, remaining only 5% of inorganic nitrogen in the 5th tank. The treated wastewater from the BMW plant sprayed on a field in an amount of 3 t/10a made a significant difference in the yam potato harvest. The treated wastewater was considered as an activated liquid fertilizer. In the lab scale model plant experiment, the BMW plant decreased 40% of COD, the CSZ plant, 60%, and the Non-Material, only 20%. The CSZ plant achieved a great purification. The great purification for the CSZ plant was due to a high dissolution of Ca^{2+} from the shell, resulted in helping to neutralize with an acid of NO_3-N and keeping an optimal condition of pH in the tanks.

KEYWORDS. Liquid Manure, Treatment, Swine, Mineral, Land Application.

INTRODUCTION

Background. Livestock farms and industries of Japan import grain of more than 18 million tons a year from US, Australia, Argentina, and other countries, which corresponds about two times of the annual production of rice crop in Japan. Rice is the Japanese staple food. Hence the manure treatment of animals is a big issue to many Japanese livestock farms and industries, where land application of the manure is limited. The latest situation is more serious as the scale of farms becomes large and the local government law regulates intensively the way of manure handling at the farms. An economically and environmentally sound method for animal waste management has been required in Japan.

Objective. We focused on a practical treatment of swine liquid manure for land application using soil and mineral in an aerated reactor. After separating the manure into solid and liquid in swine barns, the liquid manure is moved to three or four tanks sequentially. At each tank reactors are suspended with a bar or placed in baskets at the bottom and aerated with air pump. The reactor consists of soil pellet, pumice, and granite, not only promoting biological digestion of the manure but also providing some minerals in it. The soil pellet is sometimes alternated by the powdery soil, spread at the bottom of the tanks. The method using soil and mineral in an aerated reactor is called "BMW" (Nagasaki, 1995), meaning bacteria, mineral, and wastewater. After being qualified for three weeks to a month in the sequential tanks, the qualified wastewater or liquid manure, low in organic matters and rich in minerals, is used for plant cultivation as an activated fertilizer.

In this study, we investigated the wastewater quality of the BMW plant using soil, granite, and pumice as main materials, installed at a large-scale swine farm, as well as the CSZ plant using charcoal, shell, and zeolite, built at a small-scale swine farm. A land application of the treated wastewater from the BMW plant was examined to yam potato production. In addition, at lab scale model plants we investigated the purification and mineral dissolution mechanisms of the materials used in the BMW plant, the CSZ plant, and the Non-Material plant that using nothing in an aerated reactor.

MATERIALS AND METHODS

Field Plant (1)

In 1998, a treatment plant of liquid manure was built at a large-scale swine farm in Towada, Aomori, Japan. It was an experimental plant that used soil, mineral, and shell in an aerated reactor. Hence it was regarded as one of the BMW method and named as the BMW plant, as shown in Figure 1. When the BMW plant was built in 1998, there were four tanks in the plant. In 2000, the 5th tank was added to keep stable treatment condition of wastewater.

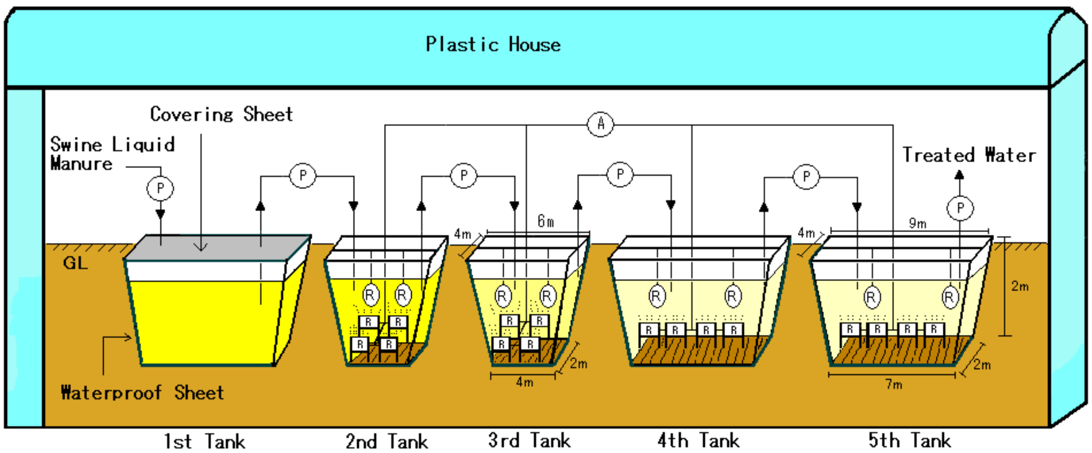

Figure 1. An experimental plant of swine liquid manure treatment, named as the BMW plant due to using soil, granite, pumice, and shell, built at a large-scale swine farm. The term A is Air Mixing Pump, P is Water Pump, and R is Aerated Reactor.

The farm fed 1,600 sows and raised 13,000 growing and finishing pigs. After separating the animal manure into solid and liquid in the swine houses, the farm produced 40 t of swine liquid manure per day. The plant consists of five tanks that are the trapezoidal holes dug in the ground and are covered with waterproof rubber sheet. There are two types of the tanks: a capacity of 50 m^3 for the large hole and 30 m^3 for the small hole. Wastewater was filled up to a volume of 70% to 90% to each tank. Furthermore the tanks were placed under a house framed with iron pipes and covered with a plastic film transparent to solar radiation to keep the tanks warm in winter.

The 1st tank was a temporary reserve of liquid manure from the swine houses, covered with a plastic sheet to protect discharge of ammonia or other odor gases. In the 2nd to the last tank, the reactors were suspended with a wooden bar or placed in plastic baskets at the bottom, and were aerated with the air pipes located under the baskets. The reactor consists of granite, pumice, and crab and scallop shell. Those materials were broken into pieces in a size of 20 mm to 80 mm and filled with a knitting plastic bag or mounted in the basket. The whole weight of the materials used in the tank was 1.0 t to 1.5 t. Soil was spread over the bottom in the 2nd to the last tank, weighing 1.0 t to 1.5 t.

Approximately at an interval of five days in summer to seven days in winter, an amount of 5 t of liquid manure was supplied to the 2nd tank. Just before this supply, treated wastewater in the same volume was moved in order from the 2nd to the last tank. To grasp a processing mechanism of the plant, pH, BOD, COD, N, P, and other water quality indices were measured for each tank. A mineral index of K^+, Na^+, Ca^{2+}, and Mg^{2+} was also measured. In addition, treated wastewater was examined for yam potato production.

Field Plant (2)

In 2002, a practical plant of liquid manure treatment using charcoal, shell, and zeolite was built at a small-scale swine farm in Towada, Aomori, Japan, as shown in Figure 2. The plant is modified of the filed plant (1). Hence it can be regarded as the modified BMW plant and named as the CSZ plant due to using charcoal, shell, and zeolite. The farm fed 50 sows and raised 500 growing and finishing pigs. Liquid manure exhausted from the swine houses was estimated in an amount of 1.6 t per day.

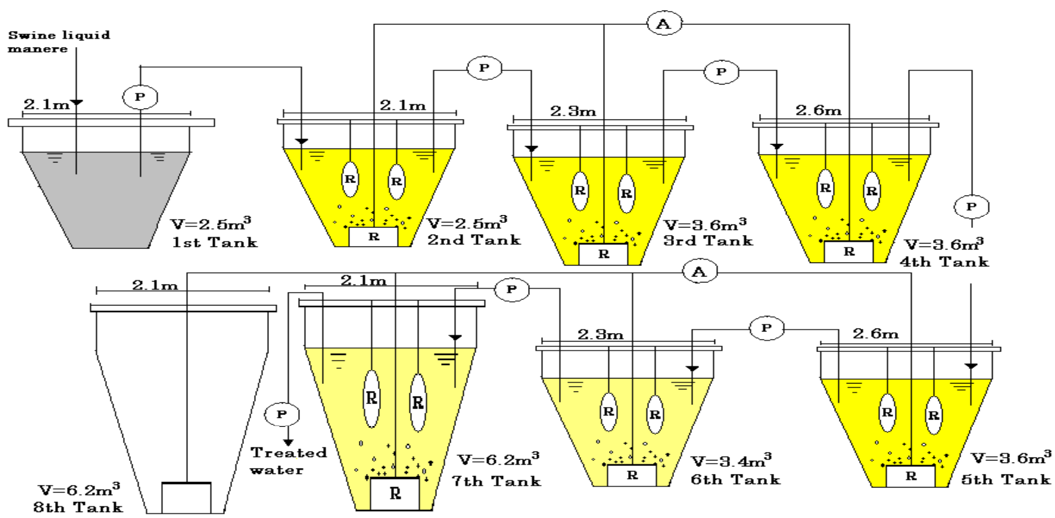

Figure 2. A practical plant of swine liquid manure treatment, named as the CSZ plant due to using charcoal, shell, and zeolite, built at a small-scale swine farm. The term P is Water Pump, A is Air Mixing Pump, and R is Aerated Reactor.

The plant consists of eight tanks in a capacity of 2 m^3 to 6 m^3. The tanks are a reuse of the dumped animal feed tank in shaping as a truncated cone and made of fiber reinforced plastic. The tanks covered inside with a waterproof plastic sheet were laid underground and installed in a plastic house to keep warm in winter. In the aerated reactor, the plant used the materials of rice husk charcoal, scallop shell, and zeolite that were agricultural processed waste, marine waste, and mining product, respectively. Those waste and product are available for swine farms in Aomori, Japan. The materials excepting rice husk charcoal were broken into pieces in a size of 20 mm to 50 mm and filled with a knitting plastic bag or mounted in a plastic basket. The bag was hung with a wooden bar and the basket was laid at the bottom of the tank. The air pipe was set under the basket. The whole weight of the materials used in the tank was about 100 kg. The 1st tank was used for a temporally reserve of the liquid manure from the swine houses.

An amount of 1 t of liquid manure was supplied daily to the 2nd tank. Just before this supply, treated wastewater in the same volume was moved in order from the 2nd to the last tank. To obtain the wastewater quality of the plant, pH, COD, N, P, and other water quality indices were measured. In addition, a mineral index of K^+, Na^+, Ca^{2+}, and Mg^{2+} was also measured.

Lab Scale Model Plant

To grasp desirable materials for swine liquid manure treatment, the purification and mineral dissolution mechanisms of the BMW materials and the CSZ materials were investigated using the lab scale model plants. At the same time, the Non-Material, meaning nothing in the aerated reactor of the plant, was also experimented as a control.

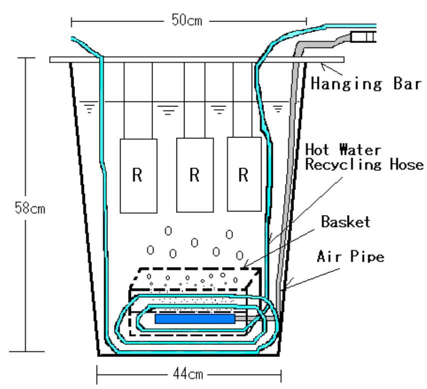

Figure 3. Cross section of a tank used in the lab scale model plant.

Figure 3 shows the cross section of a tank used in the lab scale model plant at Kitasato University. For the method of (1) BMW, (2) CSZ, and (3) Non-Material, a pair of three tanks in a volume of

90 litters was used. Air was supplied in rate of 3.5 liters per minute with an air pipe located under a basket. The basket was served as a sinker and as dispersion of air bubbles. Swine liquid manure, carried from the large-scale swine farm as mentioned in Field Plant (1), was supplied in a volume of 8 litters per day to the 1st tank. Just before this supply, treated wastewater in the same volume was moved in order from the 1st to the 3rd tank. Wastewater temperature of the tank was maintained at 20□ with circulating hot water in the hose.

Table 1 shows the materials and their quantity used in the three methods. The compound ratio of those materials for each method was based on the Field Plants (1) and (2). Those materials, excepting the soil and the rice husk charcoal, were broken into pieces in a size of 10 mm to 20 mm and filled with a knitting nylon bag hung with a wooden bar.

Table 1. Materials used in the lab scale model plants. (Unit: kg)

Method	Soil	Granite	Pumice	Rice Husk Charcoal	Scallop Shell	Zeolite
(1) BMW	4.0	2.5	0.7	–	–	–
(2) CSZ	–	–	–	1.0	1.0	1.0
(3) Non-Material	–	–	–	–	–	–

To obtain the quality change of the wastewater in the tanks for each method, pH, COD, N, P, and other water quality indices were measured. A mineral index of K^+, Na^+, Ca^{2+}, and Mg^{2+} was also measured. In addition, weight loss of the materials, excepting the soil and the charcoal was measured monthly with a balance during the three months from the beginning of the experiment.

RESULTS AND DISCUSSION

Field Plant (1)

Table 2 was obtained in 1998, when the plant of four tanks was built. At this time, the plant used granite, pumice, and crab shell in the aerated reactor and soil spread at the bottom. Sampling of the wastewater in the tanks was done monthly during from Jul to Dec 1998. In spite of great decrease in a ratio of 99% for BOD of the 1st tank to the last tank, the pH kept more than 8.0 in the 2nd to 4th tank. This supports that a conversion rate of NH_4-N to NO_3-N was low and an amount of 28% of inorganic nitrogen was remained in the last tank. K^+ gave a high density of more than 3,000 mg/*l* in the last tank despite of a large decrease of 60% to the density in the 1st tank. Ammonia gas density at the wastewater surface showed a high value of 32 ppm, but decreased to 2 ppm ~ 6 ppm in the following tanks. Odder problem did not give rise to us because of covering the 1st tank with the plastic sheet.

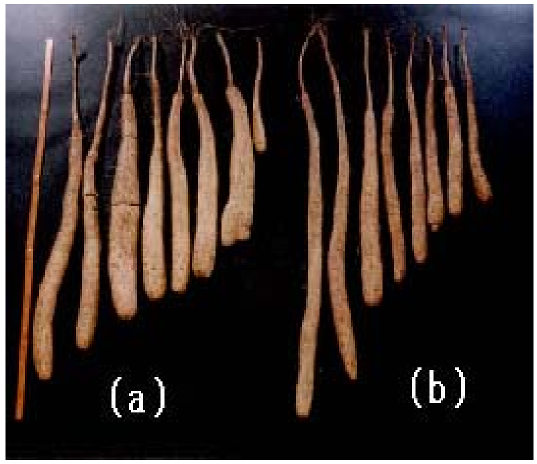

Figure 4. Comparison of yam potato harvest (Ohta et al., 2000). The treated wastewater obtained from the BMW plant was used to the yam (a) in an amount of 3 t/10a in addition to a chemical fertilizer. To the yam (b), the chemical fertilizer was only given.

Judging from the results in Table 2, the 5th tank was needed and built in 2000 to increase a rate of denitrification in the tank. In addition, scallop shell was used in the aerated reactors of the 4th and 5th tank to keep a desirable condition of pH. Wastewater quality of the five tanks measured in 2002 is given to Table 3. Although a large discrepancy of pH was observed in the 3rd tank, the 4th and 5th tank kept a preferable condition of pH. This was assumed that an ingredient of Ca^{2+} contained in the scallop shell neutralized the strong acid substance derived from the 3rd tank in the following tanks. The Ca^{2+} density increased rapidly in the 4th and 5th tank with respect to that in the 1st to 3rd tank, resulting in increasing a conversion rate of NH_4-N to NO_3-N high and remaining only an amount of 5% of inorganic nitrogen in the last tank.

Table 2. Wastewater quality and ammonia gas density of the BMW plant measured during Jul to Dec 1998.

Index	1st Tank	2nd Tank	3rd Tank	4th Tank
pH	8.8 ± 0.5*	8.0 ± 1.5	8.3 ± 0.3	8.8 ± 0.2
NH_4-N (mg/*l*)	1,820 ±240	670 ± 350	260 ± 250	-
NO_2-N (mg/*l*)	- **	20 ± 20	30 ± 50	-
NO_3-N (mg/*l*)	-	930 ± 250	250 ± 80	420 ± 270
PO_4-P (mg/*l*)	× ***	480 ± 470	260 ± 240	40 ± 10
T-P (mg/*l*)	70 ± 10	110 ± 20	170 ±10	120 ± 10
K^+ (mg/*l*)	11,520 ± 7,230	5,330 ± 5,140	3,190 ± 1,550	3,130 ± 1,920
BOD (mg/*l*)	9,060 ± 4,230	1,760 ± 940	360 ± 310	100 ± 60
COD_{Mn} (mg/*l*)	1,930 ± 210	1,280 ± 130	830 ± 310	260 ± 40
SS (mg/*l*)	5,740 ± 2,990	12,000 ± 9,510	10,250 ± 13,030	90 ± 40
NH_3 Gass (ppm)	32.0 ± 16.0	6.5 ± 1.5	2.2 ± 0.2	2.5 ± 2.5

* = mean±s.d., ** 「 」= not detected, *** 「×」= not measured.

Table 3. Water quality of the BMW plant measured during May to Dec 2002.

Index	1st Tank	2nd Tank	3rd Tank	4th Tank	5th Tank
pH	8.3 ± 0.3*	7.1 ± 0.7	2.9 ± 0.1	5.4 ± 0.4	5.8 ± 0.2
NH_4-N (mg/*l*)	2,490 ± 80	940 ± 80	380 ± 10	110 ± 10	20 ± 5
NO_2-N (mg/*l*)	10 ± 10	— **	—	—	—
NO_3-N (mg/*l*)	10 ± 10	1,010 ± 40	930 ± 70	120 ± 20	120 ± 20
PO_4-P (mg/*l*)	50 ± 10	100 ± 10	160 ± 40	120 ± 20	120 ± 30
T-P (mg/*l*)	70 ±10	110 ± 20	170 ±10	120 ± 10	130 ± 10
Na^+ (mg/*l*)	× ***	360	410	460	610
K^+ (mg/*l*)	×	1,770	2,070	2,320	3,060
Mg^{2+} (mg/*l*)	—	20	50	50	70
Ca^{2+} (mg/*l*)	—	10	—	120	90

*= mean ± s.d., ** 「-」= not detected, *** 「×」= not measured.

In a control experiment of land application of treated wastewater to crop production in 1999, comparison of yam potato harvest is shown in Figure 4. Before planting the seeds of yam potato on a field, the treated wastewater obtained from the 4th tank of the BMW plant was sprayed over the half area of the field in an amount of 3 t/10a in addition to a chemical fertilizer. To the rest of the field, the chemical fertilizer was only given. After harvested, an average of weight and length for the two groups of 27 yam potatoes was obtained. A significant difference was observed in the applied group of the treated wastewater. Hence the treated wastewater may be considered as an activated liquid fertilizer.

Field Plant (2)

Table 4. Wastewater quality of the CSZ plant measured during Jul to Nov 2002.

Index	1st Tank	2nd Tank	3rd Tank	4th Tank	5th Tank	6th Tank	7th Tank
pH	8.6 ± 0.2*	6.1	7.2	7.4	7.5	7.7	7.4
NH_4-N (mg/*l*)	1450 ± 210	90	– **	–	–	–	–
NO_2-N (mg/*l*)	10 ± 10	80	–	–	–	–	–
NO_3-N (mg/*l*)	70 ± 10	50	110	90	120	110	130
PO_4-P (mg/*l*)	30 ± 10	60	50	50	50	50	50
T-P (mg/*l*)	× ***	80	50	60	60	50	60
Na^+ (mg/*l*)	×	90	110	110	120	120	130
K^+ (mg/*l*)	×	340	470	480	500	500	540
Mg^{2+} (mg/*l*)	×	30	40	40	40	40	40
Ca^{2+} (mg/*l*)	×	70	80	60	60	60	70

*= mean ± s.d., ** 「 」= not detected, *** 「×」not measured.

After the CSZ plant using charcoal, shell, and zeolite in the aerated reactor was built in 2002, a leak test was done and liquid manure from the swine houses was added carefully to the 2nd tank. The wastewater quality of the CSZ plant was in progress after three months later from the beginning of wastewater treatment. Hence the 8th tank was not filled up with the wastewater. A density of NH_4-N was decreased remarkably to a rate of 4% at the 2nd tank, and the ingredient was not detected at the following tanks (Table 4). Inorganic nitrogen was remained a little amount of 7% in the 7th tank with respect to that of the 1st tank. Water plants and phytoplankton were observed in the 4th to 7th tank.

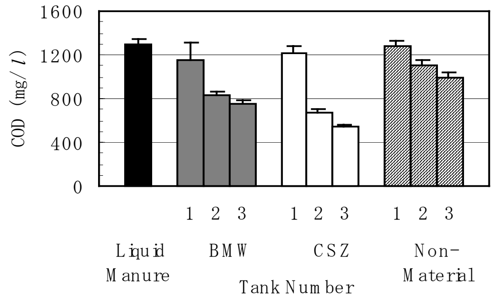

Figure 5. COD

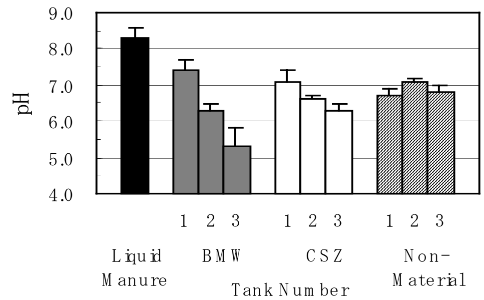

Figure 6. pH

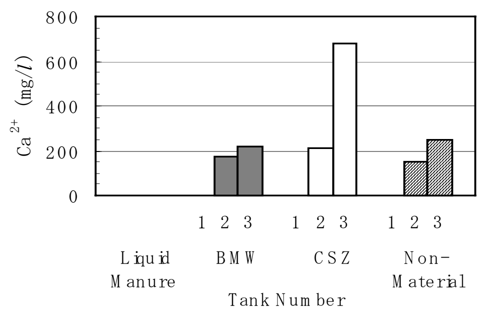

Figure 7. Ca^{2+}

<u>Lab Scale Model Plant</u>

The purification and mineral dissolution mechanisms among the pairs of materials used in the model plants of the BMW, the CSZ, and the Non-Material were investigated. As the pair of materials, the BMW model plant used soil, granite, and pumice, the CSZ, charcoal, shell, and zeolite, and the Non-Material, nothing. It needed three months to start in sampling the wastewater of the plants in a stable condition.

- COD (Figure 5): To the density of liquid manure, the BMW showed a decrease of 40% in the 3rd tank, the CSZ, 60%, and the Non-Material, only 20%. The CSZ achieved a strong purification in the 2nd and 3rd tank.
- pH (Figure 6): A weak acid more than 6 was obtained in the CSZ as well as the Non-Material. The pH of the CSZ decreased in accord with the tank number. But the pH of the Non-Material kept a constant ranging from 6.7 to 7.1. This means the Non-Material did not work well for converting NH_4-N into NO_3-N, remaining a large amount of NO_2-N more than 800 mg/*l* in all the tanks, as shown in Table 5. An acid near 5 was observed in the 3rd tank of the BMW. This acidification was derived from a large amount of NO_3-N production more than 500 mg/*l* as given to Table 5. In spite of large production of NO_3-N in the CSZ as shown in Table 5, the CSZ kept an optimal condition of pH.
- Ca^{2+} (Figure 7): About three times of Ca^{2+} production was observed in the 3rd tank of the CSZ with respect to that of the BMW and the Non-Material. This was assumed that $CaCO_3$ contained in the shell was dissolved into the wastewater and Ca^{2+} was neutralized with a high density of NO_3-N more than 700 mg/*l* as shown in Table 5. Keeping an optimal condition of pH in the CSZ tanks despite of a high density of NO_3-N, as shown in Figure 6, proved the neutralization. High dissolution of Ca^{2+} in the wastewater may play an important part in land application. Grass tetany (hypomagnesemia), a metabolic disorder of ruminants, occurs in a high rate of K and N fertilization on the soil of grasses and low forage Mg (Kemp, 1958; Stuart et al., 1973). An effective method against the grass tetany is known to supply Ca and Mg with the soil, or to decrease a ratio of K/(Ca+Mg) of the forage.
- P (Table 5): A density of T-P in all the tanks was closed to each PO_4-P. Hence phosphorus existed in an inorganic form. The PO_4-P in all the tanks was greater than the liquid manure. This was related to accumulation from the liquid manure as well as dissolution of the materials. Only the BMW decreased the density of PO_4-P in the 3rd tank in a ratio of 1/4 with respect to the 1st tank. This implies a strong absorption by the soil used in the BMW.
- Weight Loss (Table 6): The maximum loss of 15% was obtained for the scallop shell after three months. This proves strongly the high dissolution of Ca^{2+} in the CSZ tanks as shown in Figure 6. The pumice of the BMW and the zeolite of the CSZ were decreased within 10% three months later. The granite kept the original weight even after three months. The shell, zeolite, and pumice contributed to add minerals in the wastewater.

Table 5. Wastewater quality in the three model plants measured during Jun to Dec 2001.

Index	Method	Liquid Manure	1st Tank	2nd Tank	3rd Tank
NH_4-N (mg/*l*)	(1) BMW	2,490±80*	220±160	60±10	50±10
	(2) CSZ		120±20	50±10	30±10
	(3) Non-Material		650±10	490±10	320±20
NO_2-N (mg/*l*)	(1) BMW	10±10	470±40	—**	—
	(2) CSZ		510±10	—	—
	(3) Non-Material		1,040±120	910±10	810±10
NO_3-N (mg/*l*)	(1) BMW	10±10	70±10	530±10	600±10
	(2) CSZ		40±10	570±20	770±20
	(3) Non-Material		100±10	220±10	300±10
T-P (mg/*l*)	(1) BMW	70±10	260±70	140±10	60±20
	(2) CSZ		120±10	120±10	100±10
	(3) Non-Material		170±10	180±10	160±20
PO_4-P (mg/*l*)	(1) BMW	50±10	260±20	140±10	60±10
	(2) CSZ		100±10	120±10	100±10
	(3) Non-Material		170±10	180±20	160±10
K^+ (mg/*l*)	(1) BMW	1,890	2,880	4,190	3,920
	(2) CSZ		3,720	4,200	5,910
	(3) Non-Material		2,830	3,490	4,480
Na^+ (mg/*l*)	(1) BMW	360	680	900	830
	(2) CSZ		870	940	1,310
	(3) Non-Material		560	690	930
Mg^{2+} (mg/*l*)	(1) BMW	—	—	—	60
	(2) CSZ		—	70	40
	(3) Non-Material		—	—	—

* = mean ± s.d., ** 「 」= not detected.

Table 6. Monthly weight loss of the materials. (Unit: g)

Method	BMW				CSZ			
	Material	1st Tank	2ed Tank	3rd Tank	Material	1st Tank	2ed Tank	3rd Tank
Start	Pumice	700 (100%)			Scallop Shell	1,000 (100%)		
1 month later		700 (100%)	690 (99%)	700 (100%)		990 (99%)	990 (99%)	990 (99%)
2 months later		700 (100%)	670 (96%)	670 (96%)		940 (94%)	900 (90%)	900 (90%)
3 months later		690 (99%)	670 (96%)	650 (93%)		910 (91%)	870 (87%)	850 (85%)
Start	Granite	2,500 (100%)			Zeolite	1,000 (100%)		
1 month later		2,500 (100%)	2,500 (100%)	2,500 (100%)		1,000 (100%)	1,000 (100%)	990 (99%)
2 months later		2,500 (100%)	2,500 (100%)	2,500 (100%)		990 (99%)	990 (99%)	950 (95%)
3 months later		2,500 (100%)	2,500 (100%)	2,500 (100%)		990 (99%)	950 (95%)	920 (92%)

CONCLUSIONS

- Using the additional 5th tank and the scallop shell in the aerated reactors, the BMW plant kept a preferable condition of pH in the 4th and the 5th tank and increased a conversion rate of NH_4-N to NO_3-N, remaining only 5% of inorganic nitrogen in the 5th tank with respect to that of the 1st tank.
- The treated wastewater from the BMW plant sprayed on the field in an amount of 3 t/10a made a significant difference in the yam potato harvest. The treated wastewater may be considered as an activated liquid fertilizer.
- In the lab scale model plant experiment, the BMW plant using soil, granite, and pumice, decreased 40% of COD, the CSZ plant using charcoal, shell, and zeolite, 60%, and the Non-Material using noting, only 20%. The CSZ plant achieved a great purification.
- The great purification for the CSZ plant was due to a high dissolution of Ca^{2+} from the shell, resulted in helping to neutralize with an acid of NO_3-N and keeping an optimal condition of pH in the tanks.
- To design a more effective CZS plant, further research is needed on developing a greater database as well as finding an optimal mass and volumetric combination of the materials of charcoal, shell, and zeolite, a chemical function of each material, and a land application to many crops.

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