Methane Fermentation of Night Soil Sludge and Kitchen Waste Mixture

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NKK developed a new treatment process called the RENAISSA System® that treats a mixture of night soil sludge and kitchen waste under anaerobic conditions. The system produces energy and compost for agricultural use. This paper describes some characteristics of the new process that were developed during pilot plant testing conducted from May 1998 until February 1999.

1. Introduction

In recent years, a range of environmental problems resulting from human economic activity has become apparent. The most notable of these problems are global warming due to greenhouse gases and pollution of the environment with dioxins. These problems are causing increasing and widespread concern for the environment.

This concern has led to the reassessment of a society based on mass production and mass consumption, and a movement focusing on building a socio-economic system for recycling of resources is becoming increasingly active.

Society is making increasingly strong demands for reducing the volume of waste material, effectively using these waste materials as resources, and processing them appropriately.

In response to these demands, the Ministry of Health and Welfare developed the concept of a "sludge reclamation treatment center" for night soil treatment in 1997 and is currently actively engaged in its promotion and proliferation. These night soil treatment facilities not only process night soil and sludge from septic tanks, but also include organic wastes such as kitchen waste. Mixtures of night soil sludge and kitchen waste are fermented to produce methane and compost as a means of recovering energy and resources and effectively using organic waste materials produced in a local area.

Within this context, NKK, Ishikawajima-harima Heavy Industries Co., Nippon Steel Corp., Takuma Co., Toray Engineering Co., Hitachi Zosen Corp., and Mitsui Engineering & Shipbuilding Co. formed a cooperative venture to introduce methane fermentation technology from the German company Schwarting-Uhde GmbH, which is well known for its experience in a wide range of processing technologies for organic waste.

In addition to the development of the RENAISSA System® sludge reclamation treatment process, the venture operated a pilot plant for approximately ten months between May 1998 and February 1999 at the Environmental Center of Kamiukena-gun Environmental Association in Ehime Prefecture.

This paper outlines the results obtained from operation of the pilot plant.

2. Experimental method

2.1 Processing flow and process

Combining the RENAISSA System® technology with existing night soil treatment processes allows the recovery of valuable resources such as methane and compost using sludge and organic wastes. The technology comprises a methane recovery process, which consists of pre-processing equipment and methane fermentation equipment, and a resource recovery process, which consists of sludge reclamation equipment.

Features of this technology are as follows.

(1) A mixture of sludge and pre-processed kitchen waste is processed to reduce its volume.

(2) Methane fermentation produces more energy than is required to heat the digester.

(3) Liquid is removed from the sludge after the methane fermentation stage, and the sludge is then composted to recover additional available resources.

(4) The liquid removed from the sludge after the methane fermentation process may be processed in a conventional

night soil treatment facility.

The processing flow used in the pilot plant is shown in **Fig.1**. The various processes employed are outlined below.

(1) Pre-processing

Pre-processing is used to control the physical properties of the kitchen waste and sludge. Kitchen waste obtained from facilities such as supermarkets, hospitals, farms, and hotels was supplied to the pilot plant. The plastic wastes bags were then broken open, the refuse crushed and sorted, the DS concentration adjusted to approximately 10% and the particle size adjusted to a maximum of 10mm.

The sludge used was dehydrated excess sludge obtained from existing night soil treatment facilities. The DS concentration of the sludge was adjusted to approximately 10%.

Pre-processed kitchen waste and sludge for a single day's processing were mixed in an intermediate tank and left to stand for a day. The contents of the tank were then introduced into the digester in four lots. This procedure was conducted every day except Sunday.

(2) Fermentation

The microorganisms employed in methane fermentation require accurate control of the processing temperature to facilitate the fermentation reaction. Most fermentation processes employ either medium temperature fermentation (37℃) or high temperature fermentation (55℃). Medium temperature fermentation ensures stable processing, while high temperature fermentation provides a high rate of methane production.

This system uses two digesters, the first is for medium temperature fermentation, and the second is for high temperature fermentation. The first stage is used for stable fermentation of organic materials at low energy levels, while the second stage provides high-speed fermentation of the remaining organic materials to increase the volume of methane recovered.

(3) Dehydration of removed sludge and conversion to compost

A dehydration agent is added to the sludge removed from the digesters, and the sludge is concentrated and de

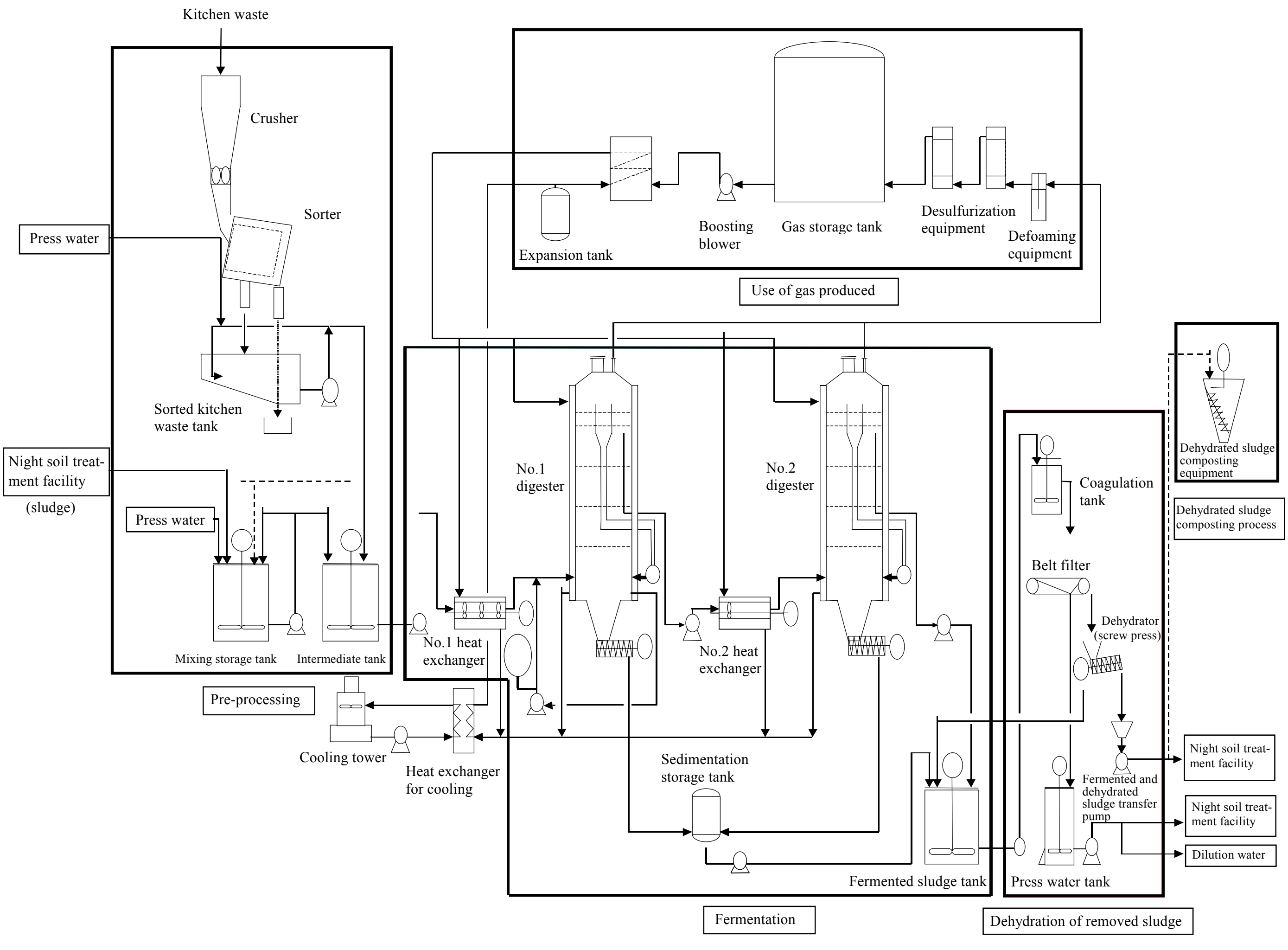

Fig.1 Pilot plant processing flow

hydrated using a belt filter and screw press. Fowl droppings are added to the sludge cake in the composting unit, where the temperature is maintained at approximately 60℃ to promote aerobic fermentation.

(4) Use of gas produced

The gas obtained from the fermentation process is used as fuel in hot water boilers, and energy is recovered as heat. In a practical, large-scale system, fermentation could provide fuel for a gas engine to power an electric generator for energy recovery.

2.2 Test conditions

After trial operation using only sludge for fermentation, a series of tests was conducted under the conditions indicated in **Table 1**. The amount of fermentation material introduced was maintained at 3150 kg/d. Processing performance was investigated by altering the sludge mixture ratio (VTS in the sludge to the total VTS in the fermentation material).

For each run, the run-up period was set at approximately one month, and the test was then conducted for a period of 2～4 weeks while data was recorded.

Table 1 Test conditions

Item	Fermentation material	Weight of material introduced			DS concentration	Sludge mixture ratio
		VTS	DS	Wet weight (amount)		
Unit	－	kg/d	kg/d	kg/d	%	[－]
RUN 1	Sorted kitchen waste	158.1	196	2000	9.81	
	Sludge	75.4	115	1150	9.97	0.32
	Total	233.5	311	3150	9.87	
RUN 2	Sorted kitchen waste	110.7	126	1480	8.50	
	Sludge	106.4	153	1670	9.19	0.49
	Total	217.1	279	3150	8.87	
RUN 3	Sorted kitchen waste	101.8	107	1200	8.90	
	Sludge	123.2	178	1950	9.13	0.55
	Total	225.0	285	3150	9.05	

3. Test results

3.1 Properties of fermentation materials

Table 2 shows the composition of the fermentation materials used. An analysis of the kitchen waste and sludge components indicate that the kitchen waste had a high concentration of organic index components, such as VTS and CODcr, carbohydrates, and fats, while the sludge had a high concentration of T-N and proteins.

Table 2 Compositions of fermentation materials (n=10)

※n=9

	Item	Unit	Average	Maximum	Minimum
Kitchen waste	pH		4.5	5.3	3.8
	DS	%	10.4	13.0	9.0
	VTS	%・dry	90.8	93.3	85.6
	CODcr	mg/L	153600	179600	129200
	NH4-N	mg/L	630	1300	160
	T-N※	%・dry	0.53	0.88	0.40
	Carbohydrates※	%・dry	10.9	26.0	4.0
	Proteins※	%・dry	28.9	34.4	24.4
	Fats※	%・dry	26.0	38.4	20.1
Sludge	pH		7.2	7.8	6.8
	DS	%	10.0	10.7	9.5
	VTS	%・dry	69.8	73.9	65.5
	CODcr	mg/L	101600	120000	88300
	NH4-N※	mg/L	930	2000	170
	T-N※	%・dry	0.61	0.76	0.50
	Carbohydrates※	%・dry	5.2	10.6	3.9
	Proteins※	%・dry	33.7	40.0	29.8
	Fats※	%・dry	6.0	9.0	5.6

3.2 Fermentation test results

(1) Gas generated

Fig.2 shows the time variation for both the volume of fermentation material introduced and the amount of gas generated over time for RUN 2. The amount of gas generated was a minimum on Sundays, when no fermentation material was introduced, and then increased over the remainder of the week. During this run (November 9th through December 5th), gas was produced at a rate of 60 to 130 Nm^3/day, with an average value of 104Nm^3/day.

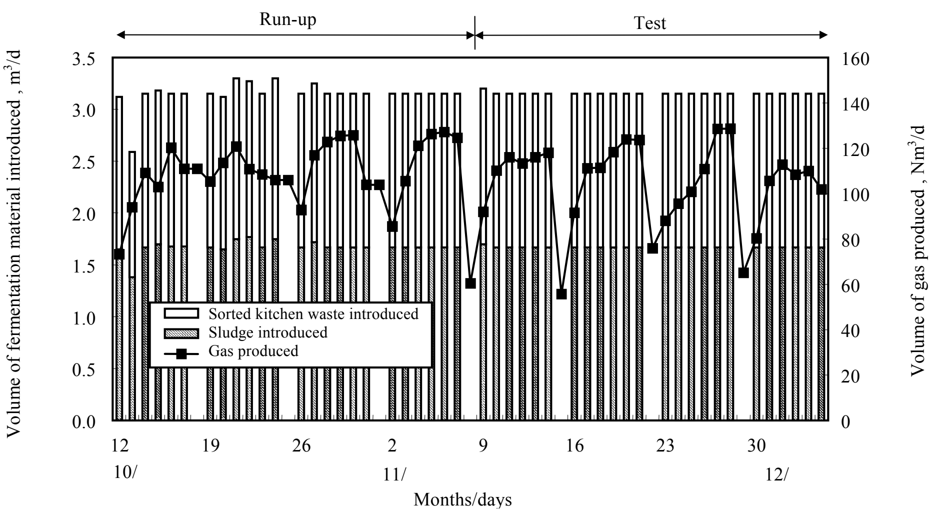

Fig.2 Volume of fermentation material introduced, and amount of gas generated over time (RUN 2)

(2) DS and VTS

DS and VTS concentrations during RUN 2 are shown in **Fig.3**.

Both the DS and VTS concentrations tended to decrease through the process, from the intermediate tank, to the No.1 digester outlet, and then to No.2 outlet. This is due to the decomposition of DS and VTS in the gasification of organic materials during the methane fermentation process. The variation in DS and VTS concentrations in the No.1 digester outlet was extremely small compared to that in the intermediate tank. This suggests that medium temperature fermentation contributed to smoothing the load changes in the fermentation material.

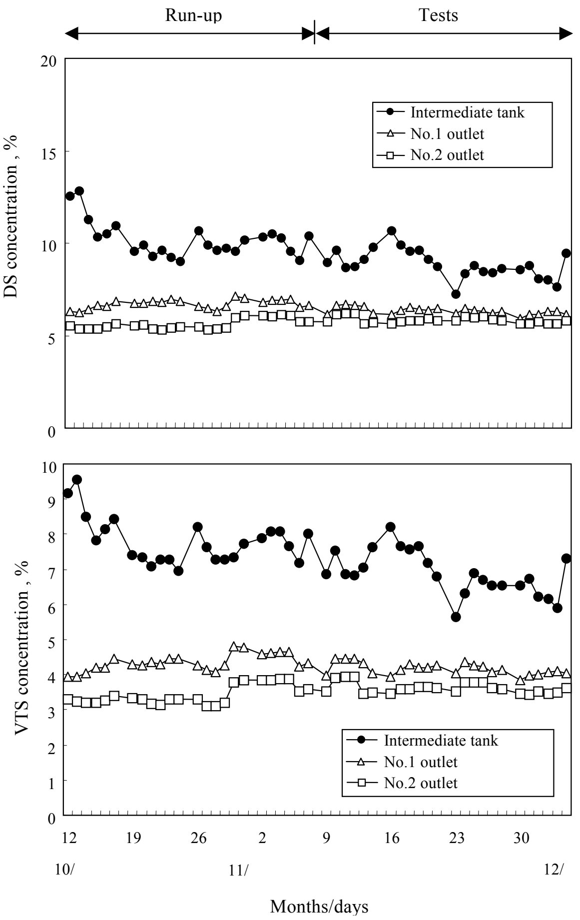

Fig.3 DS and VTS concentrations over time

(3) Ammonia nitrogen

The concentration of ammonia nitrogen during RUN 2 is shown in **Fig.4**. The ammonia nitrogen concentration tended to increase through the process, from the intermediate tank, to the No.1 digester outlet, and then to No.2 outlet. The average concentration at No.2 outlet was 3275 mg/L. This tendency could be due to the fact that organic nitrogen such as protein in the fermentation material decomposes anaerobically into ammonia nitrogen in the fermentation process.

The concentration of ammonia nitrogen was nearly constant during the test, suggesting the stable decomposition of proteins, etc.

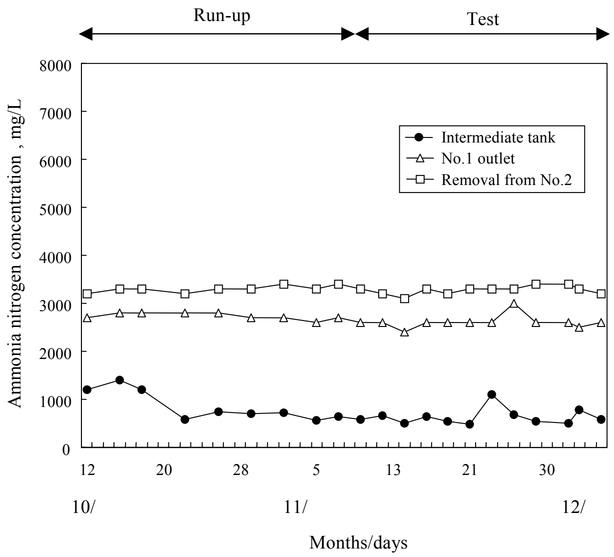

Fig.4 Ammonia nitrogen concentration over time (RUN 2)

(4) Carbohydrates, proteins, fats

Organic materials were analyzed in terms of carbohydrates, proteins, and fats, as shown in **Fig.5**. The highest decomposition rate for carbohydrates, proteins, and fats was obtained in RUN 1, which had the lowest sludge mixture ratio. On the other hand, RUN 2 and RUN 3, in which the sludge mixture ratio was comparatively high, exhibited a lower rate of decomposition for carbohydrates and proteins due to the relatively large proportion of constituents that do not readily ferment. A high decomposition rate (approximately 60%) was obtained for fats under all test conditions.

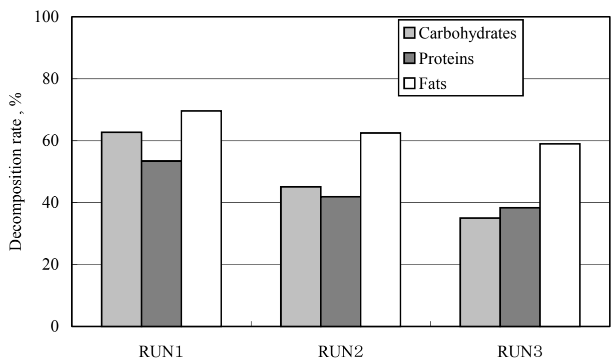

Fig.5 Decomposition rates for carbohydrates, proteins, and fats

3.3 Characteristics of methane fermentation

(1) Material balance

Table 3 shows the material balance for the digester under the test conditions employed. As shown in the table, the VTS load for the startup was 4.11 to 4.42kg/m^3, ensuring that the equipment was operated at similar loads for all of the test conditions.

The decomposition rate for organic materials, as indicated by both VTS and CODcr indices, increased in the order of RUN 1, RUN 2, and RUN 3. A low sludge mixture ratio tended to be associated with a high decomposition rate, while a high sludge mixture ratio was associated with a low decomposition rate, following the same trend as noted above for the three organic material elements (carbohydrates, proteins, fats).

The volume of gas generated from the organic material was 0.551 Nm^3/kg-VTS for RUN 1, 0.540 Nm^3/kg-VTS for RUN 2, and 0.485 Nm^3/kg-VTS for RUN 3. This indicates a tendency for a high volume of gas to be generated with low sludge mixture ratios. Thus, methane fermentation may decompose the sorted kitchen waste more easily than the sludge.

It is well known that the theoretical volume of gas generated by CODcr decomposition is 0.35 Nm^3/kg-decomposed CODcr. As seen in **Table 3**, very good agreement was obtained between the theoretical and actual values.

Table 3 Material balance for each run

		Unit	RUN 1	RUN 2	RUN 3
VTS amount	Sorted kitchen waste	kg	2372	2656	2444
	Sludge	kg	1131	2554	2957
	Total	kg	3503	5210	5401
VTS decomposition rate		%	55.8	49.2	46.8
VTS load		kg/m^3・d	4.42	4.11	4.26
Weight of CODcr introduced		kg	5865	8855	9333
CODcr decomposition rate		%	58.3	56.2	52.1
Volume of gas generated		Nm^3	1930	2813	2621
Gas generated per unit of VTS		Nm^3/kg・VTS	0.551	0.540	0.485
Volume of methane gas generated		Nm^3/kg.decomposed CODcr	0.336	0.347	0.333

(2) Characteristics of two-stage fermentation

The test employed two-stage (medium and high-temperature) fermentation, and residual organic material that was not completely fermented in the first stage was almost completely decomposed in the second stage.

Table 4 shows the decomposition rates for CODcr and VTS in each digester, along with the No. 2 digester contribution (ratio of the decomposition rate in the No.2 digester to the total breakdown during fermentation). As shown in the table, no dramatic differences in No.2 digester contribution for CODcr were apparent under the test conditions, with all values being about 10%.

RUN 1, which had the lowest sludge mixture ratio, exhibited a relatively high decomposition rate for VTS in the No.1 digester, and the No.2 digester contribution was comparatively low at 12.4%. On the other hand, the contribution of the No.2 digester for RUN 2 and RUN 3, which had high sludge mixture ratios, was relatively high, at 16.0% and 14.5%, respectively.

These results indicate that the role of the No.2 digester in the decomposition of organic materials becomes relatively greater with high sludge mixture ratios. Other research[1] has shown that satisfactory results are possible with high-temperature fermentation at higher VTS loads than used in this test. Thus, the accommodation of higher VTS loads is quite possible with the two-stage fermentation process in this system.

It is well known that exposure to a high-temperature for a certain period of time kills pathogenic bacteria, and that the time required is reduced as the temperature is increased. Sterilization for *Salmonella*, dysentery bacillus, and cholera vibrio require a temperature of 55℃ over a period of seven days, while salmonella typhi, *Staphylococcus aureus*, pyogenic streptococci, and *Diphtheria* require a temperature of 50 to 60℃ for up to seven days[2].

On this basis, containment of the fermentation materials in the second stage for a period of seven days or more at a high-temperature of approximately 55℃ promises to provide satisfactory processing results, as well as health and hygiene benefits.

Table 4 Decomposition rates for COD and VTS in each digester, and contribution of No.2 digester

Units : %

	CODcr			VTS		
	Decomposition rate		Contribution of No.2 digester	Decomposition rate		Contribution of No.2 digester
	No.1 digester	No.2 digester		No.1 digester	No.2 digester	
RUN 1	52.2	58.3	10.5	48.9	55.8	12.4
RUN 2	50.9	56.2	9.5	41.3	49.2	16.0
RUN 3	46.4	52.1	11.0	40.1	46.8	14.5

3.4 Composting of methane fermentation residue

(1) Characteristics of compost

An analysis of the compost obtained from RUN 3 is shown in **Table 5** along with the standard values for quality of night soil sludge compost and night soil sludge fertilizer provided by the Central Union of Agricultural Cooperatives. As shown in the table, the compost obtained from this system easily satisfies the requirements for night soil sludge compost along with all requirements for night soil sludge fertilizer except moisture content.

An elution test of the compost was performed in accordance with the method detailed in Environmental Agency Notification No.13. The results demonstrated that the concentration of toxic materials such as heavy metals and cyanide compounds in the solution was within the values set for metals in industrial waste.

Table 5 Compost analysis (RUN 3) and quality standards

Item	Unit	Analysis	Quality standards (supplied by Central Union of Agricultural Cooperatives)	
			Night soil sludge compost	Night soil sludge fertilizer
pH		8.4	8.5max.	8.5max.
Moisture content	%	41.0	50max.	30max.
VTS	%・dry	63.0	35min.	35min.
C/N	−	9.9	20max.	10max.
P_2O_5	%・dry	12.4	2min.	2min.
T-N	%・dry	3.5	2min.	2min.
Alkali content	%・dry	6.8	25max.	25max.

(2) Biotoxicity and fertilizer effects

The dehydrated cake remaining after methane fermentation in RUN 2 and the compost were tested to determine possible toxic and fertilizer effects on vegetation when used as a fertilizer. Dried somatic cell fertilizer obtained from a beer manufacturing plant was also employed as a control for fertilizing Chinese spinach seedlings.

Fertilizer was applied in biotoxicity tests on Chinese spinach seedlings in steps of nitrogen (N) volume from 0.1 to 0.4g to determine whether or not the growth of the seedlings was affected, both during and after germination. The first day of germination, rate of germination for the dehydrated cake and compost fertilizers, and growth following germination were similar or better than those for the somatic cell fertilizer. No abnormal symptoms were observed during the process that could be attributed to toxic materials in the tested fertilizers.

The fertilizer effect was investigated using Chinese spinach seedlings. N and K_2O were applied in the amount of 0.5g for the tested fertilizer and 0.04～0.05g for the control fertilizer. P_2O_5 was applied in the tested and control fertilizers in amounts of 1g and 0.3g, respectively.

Tests were also conducted both under standard conditions and without the application of fertilizer. The fertilizer was a normal compound fertilizer containing an equivalent of 0.35 mg each of N, P_2O_5, and K_2O.

Photo 1 shows the effects of fertilizer on the Chinese spinach seedlings. Both Sample A (dehydrated cake) and Sample B (compost) exhibited improved growth in comparison to the sample with the control fertilizer.

After 29 days of cultivation, the aboveground weight of vegetation (stems and leaves) was 80.1g for Sample A and 70.1g for Sample B. Both of these results were significantly greater than the 55.9g obtained with the dried somatic cell fertilizer.

The results of these tests indicate that the dehydrated cake and compost obtained from this system are more effective than the dried somatic cell fertilizer.

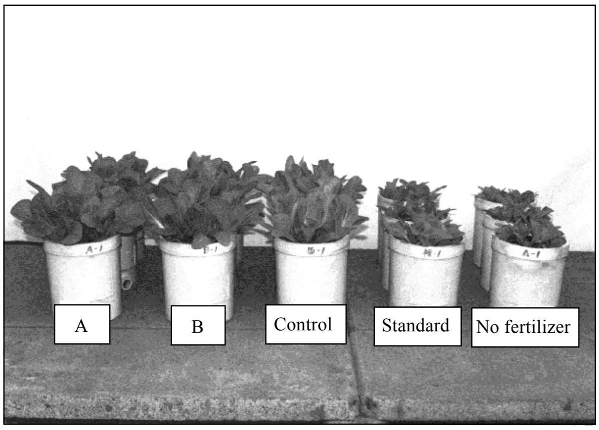

Photo 1 Growth of Chinese spinach seedlings (cultivated for 29 days)

3.5 Effects on existing night soil treatment systems

Application of the RENAISSA System® to existing night soil treatment facilities will likely involve the use of excess sludge from the existing night soil treatment facility as the raw material for methane fermentation. Moreover, the dehydrated press water will be returned to the raw water intake of the existing night soil treatment facility. It is possible that the processing performance of the night soil treatment facility may be affected when contaminants from the dehydrated press water form a major portion of the increase in load.

The ratio of dehydrated press water to the raw water (increase ratio) is shown in **Fig.6** as related to the load of contaminants on the existing night soil treatment facility. This diagram shows the relative increase ratios for BOD and T-N, although this rate is within approximately 10% for all water quality components. This test series involved continued operation with an existing night soil treatment facility, including the return of dehydrated press water, and progressed without problems affecting its operation.

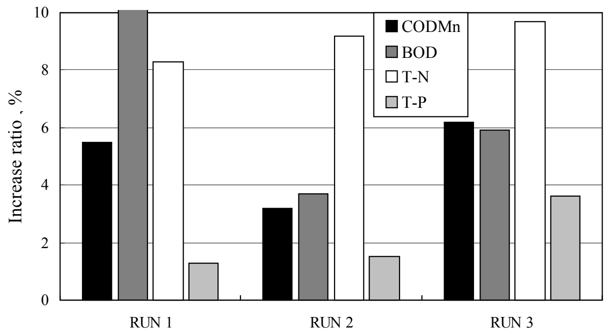

Fig.6 Rate of increase in load due to press water

4. Conclusions

This research was conducted under a technical development support project of the Japan Waste Research Foundation and was a cooperative effort of seven companies. The results obtained may be summarized as follows.

(1) Apart from the short run-up period during which conditions varied, the RENAISSA System® exhibited stable processing performance with only minimal effects of the return of dehydrated press water on the water treatment process.

(2) A considerable volume of methane gas was generated for the amount of introduced VTS - a minimum of $0.5Nm^3$/kg-VTS. The two-stage fermentation system designed in-house exhibited satisfactory processing performance.

(3) Compost produced from the residue of the methane fermentation process exhibited a superior fertilizer effect compared to the dried somatic cell fertilizer employed as the control. No evidence of inhibited growth was apparent.

Based on these results, the Japan Waste Research Foundation obtained certification of this process in January 2000 as Evaluation Technology No.23 - Methane Fermentation Technology Using Waste Water Sludge (e.g., night soil sludge) and Other Organic Waste Materials.

This approval should allow the use of the RENAISSA System® to satisfy the expected increase in demand for processes used in sludge recycling centers and provide high levels of processing performance, ease of maintenance and management, and improved economy.

The authors wish to express their appreciation for the loan of the test site and other facilities at the Environmental Center of Kamiukena-gun Environmental Association in Ehime Prefecture.

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