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LABORATORY EXPERIMENT BASED ON IN-SITU LANDFILL ANAEROBIC-AEROBIC CHANGEOVER CONTROL AND WATER SUPPLYING FOR METHANE GAS COLLECTION AND WASTE STABILIZATION

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ABSTRACT

The realization toward a sustainable loop-style exploitation society has involved various processes all over the world, one of which is how to effectively use the waste that had been piled up at final landfill disposal sites. So many researches on this problem have been reported. However, they were often uniquely and separately conducted by country to country. From a point of view of international contribution, it would be much better if the results of those researches are mutually shared and effectively extended for use under international research cooperation for making potentially new achievements.

For international cooperation and contribution, a research on the dumping waste of final landfill site is carried out at the Research Institute NPOLS in cooperation with Sudokwon Landfill site management Corporation (SLC) of South Korea in 2006. The research title is “Final disposal landfill of anaerobic-aerobic changeover style for collecting methane gas as well as early stabilizing dumping waste”. According to this research, it is considered that collecting methane gas generated from landfill dumping waste and rationally using it for producing electric energy, and promoting discharge of decomposed organic components and heavy metals from dumping waste in early stabilization should be designed as a definite landfill control method. It is explained that, depending on the waste’s characteristics at voluntarily phase (stage), periodically alternating the created atmosphere inside the dumping waste layer from anaerobic to aerobic condition, as well as sprinkling the dumping waste with water to change its water quality and amount will force the waste to generate methane gas and be stabilized in suitable landfill condition.

In this cooperative research, Column tests are carried out at SLC experimental site using general waste and incineration ash from South Korea. From total 6 Column tests, five cases (Cases 1 ~ 5) involved general waste containing fresh materials, and the left one (Case 6) is filled up with incineration ash. Since beginning experiment in Nov. 2006 to present, these 6 columns were kept in anaerobic condition and periodically sprinkled with water. The sprinkling water amounts were different, as 0.5L/week for cases 1, 2 and 6, and 1.0L/week for cases 3, 4 and 5. In all cases except for the case 1, the water exuded from the column was circulated.

To report the experimental process, this paper presents experimental outlines as well as various data analysis results and discussions.

Keywords: methane gas, stabilization, anaerobic-aerobic, landfill

INTRODUCTION

The realization toward a sustainable loop-style exploitation society has involved various processes all over the world, one of which is how to effectively use the waste that had been piled up at final landfill disposal sites. So many researches on this problem have been reported. However, they were often uniquely and separately conducted by country to country. From a point of view of international contribution, it would be much better if the results of those researches are mutually shared and effectively extended for use under international research cooperation for making potential new achievements.

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A series of column tests was carried out. In this paper, column test layout, dumping waste characteristics and results of various data analysis for a testing period from beginning to present are reported.

PURPOSES OF STUDY

The two main purposes of this study are:

1) To confirm the method of effectively generating methane gas from the landfill dumping waste;
2) To examine the method of promoting stabilization of landfill dumping waste.

In his experimental study, 6 column tests are conducted, all of which have been set up with anaerobic condition at the beginning. The anaerobic condition that is purposely set for collecting methane gas, is also expected to be good for follow up stabilizing because difficultly decomposed raw materials would be gasified and hence easily stabilized under this condition.

EXPERIMENTAL OUTLINES:

Purposes of the column tests

In this experiment, 6 column tests were carried out, among which 5 columns used general municipal waste and the other one used incineration ash from South Korea. For each column test, depending on alteration of air supplying pattern and water supplying amount, differences in amount, speed and composition of the generated gas were measured. At the same time, the inside temperature of the column, the amount and properties of exuded water were analyzed to clarify the column condition.

The used dumping waste

Material for filling up the columns 1 to 5 were relatively composed of dumping waste from the 2005 bring-in waste (general living activity waste) in 2005 of South Korea metropolitan landfill. This bring-in waste material was cut by scissors in to pieces of 20 ~ 30mm for making test samples. The compositions of the general dumping waste used for the column tests 1 to 5 are summarized in Table 1, which indicates that about 97% of the waste is combustible.

On the other hand, compositions of three components of the used general dumping waste and incineration ash

Table 1 General dumping waste compositions

Combustible					Incombustible		
Vinyl	Paper	Fiber	Wood	Raw material	Glass	Metal	Other
39.42	38.07	5.2	2.04	11.96	2.15	1.13	0.03
96.69					3.31		
100							

are shown in Table 2, while the component element analysis and the amount of generated heat are shown in Table 3. The physical properties of the used materials such initial weight, density and dry weight, initial weight of water, initial water ratio and initial content are presented in Table 4 for all tested columns.

As seen from Table 2, when the combustible component is of about 65%, the incineration reduction weight is about 2%. From Table 3, up to 53% of the general dumping waste was carbon (C). From Table 4, the initial water content was 21.7% for columns 1 to 5, and 3.5% for column 6.

Next, decomposing potentials (such as easy, difficult or unable decomposition) of the general dumping waste used in filling up columns of cases 1~ 5 are established in Table 5. Actually, in South Korea, directly dumping of raw waste to the landfill has been prohibited since 2005. Therefore, by thoroughly management of separately collecting raw waste, at present the percentage of the raw waste is about 12% lower than in the past. In 1gram of the tested material, the ratio C/N was 48, which is out of the suitable range (C/N = 10 ~ 20) for methane generation. This is considered due to the fact that the used dumping waste was relatively less material rich in N such as raw waste.

Photos 1 and 2 illustrate the tested general dumping waste and incineration ash, respectively.

Table 2 Compositions of three components of general dumping waste and incineration ash (percentage)

<table>
<tr><th colspan="2">Classification</th><th>Water</th><th>Ash</th><th>Combustible</th></tr>
<tr><td rowspan="7">General dumping waste</td><td>Vinyl/Plastic</td><td>6.65</td><td>11.73</td><td>81.62</td></tr>
<tr><td>Paper</td><td>25.05</td><td>15.66</td><td>59.29</td></tr>
<tr><td>Fiber</td><td>4.20</td><td>14.94</td><td>80.86</td></tr>
<tr><td>Wood</td><td>12.75</td><td>9.46</td><td>77.79</td></tr>
<tr><td>Raw material</td><td>43.47</td><td>19.75</td><td>36.78</td></tr>
<tr><td>Incombustible</td><td>0.0</td><td>3.31</td><td>0.0</td></tr>
<tr><td>Weighted average efficiency</td><td>17.83</td><td>17.23</td><td>64.94</td></tr>
<tr><td colspan="2">Incineration ash</td><td>3.38</td><td>94.66</td><td>1.96 (incinerated volume reduction)</td></tr>
</table>

Table 3 Component element analysis and amount of heat generation from general dumping waste and incineration ash

<table>
<tr><th colspan="2" rowspan="2">Classification</th><th colspan="5">Element analysis (%)</th><th colspan="2">Generated heat (cal/kg)</th></tr>
<tr><th>C</th><th>H</th><th>O</th><th>N</th><th>S</th><th>Low position</th><th>High position</th></tr>
<tr><td rowspan="6">General dumping waste</td><td>Vinyl/Plastic</td><td>79.1</td><td>7.0</td><td>8.9</td><td>0.9</td><td>ND</td><td>8849.1</td><td>9,267</td></tr>
<tr><td>Paper</td><td>34.6</td><td>4.6</td><td>42.3</td><td>0.3</td><td>ND</td><td>2226.3</td><td>2,625</td></tr>
<tr><td>Fiber</td><td>54.7</td><td>5.2</td><td>36.7</td><td>0.7</td><td>ND</td><td>5203</td><td>5,509</td></tr>
<tr><td>Wood</td><td>47.6</td><td>5.7</td><td>43.8</td><td>0.5</td><td>ND</td><td>4632.7</td><td>5,017</td></tr>
<tr><td>Raw material</td><td>39.0</td><td>5.0</td><td>34.9</td><td>2.7</td><td>ND</td><td>3394.18</td><td>3,925</td></tr>
<tr><td></td><td>52.8</td><td>5.50</td><td>26.6</td><td>0.84</td><td>ND</td><td>5106.9</td><td>5,510.6</td></tr>
<tr><td colspan="2">Incineration ash</td><td></td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td>—</td><td>—</td></tr>
</table>

Table 4 Column initial index properties

Column	1	2	3	4	5	6
Filling up waste	General dumping waste			Incineration ash		
Column volume (cm3)	26494	26494	26494	26494	26494	26494
Initial weight (g)	11127	10332	10597	11922	10597	42125
Initial density (g/cm3)	0.42	0.39	0.40	0.45	0.40	1.59
Initial dry weight (g)	9143	8490	8708	9796	8708	42125
Initial weight of water (g)	1984	1842	1889	2126	1889	1424
Initial water ratio (%)	17.83	17.83	17.83	17.83	17.83	3.38
Initial water content (%)	21.70	21.70	21.70	21.70	21.70	3.50

Table 5 General dumping waste types

<table>
<tr><th rowspan="3">Type</th><th colspan="4">General dumping waste</th></tr>
<tr><th colspan="2">Decomposible</th><th rowspan="2">Non-decomposible</th><th rowspan="3">Total</th></tr>
<tr><th>Easily decomposable</th><th>Difficultly decomposable</th></tr>
<tr><td>Component</td><td>Raw waste
Paper</td><td>Fiber
Wood</td><td>Vinyl
Non-combustible (glass, metal, others)</td></tr>
<tr><td rowspan="2">Percentage by weight (%)</td><td>50.03</td><td>7.24</td><td rowspan="2">42.83</td><td rowspan="2">100</td></tr>
<tr><td colspan="2">57.17</td></tr>
<tr><td rowspan="2">Organic dry weight DS (g/kg)</td><td>353</td><td>68</td><td rowspan="2">401</td><td rowspan="2">822</td></tr>
<tr><td colspan="2">421</td></tr>
<tr><td rowspan="2">Organic Concentration (g/kg)</td><td>270</td><td>58</td><td rowspan="2">—</td><td rowspan="2">—</td></tr>
<tr><td colspan="2">328</td></tr>
<tr><td rowspan="2">Ratio C/N</td><td>41</td><td>82</td><td rowspan="2">—</td><td rowspan="2">—</td></tr>
<tr><td colspan="2">48</td></tr>
</table>

Photo 1 general dumping waste

Photo 2 incineration ash

Table 6 Test cases

Case	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Fill up Waste	General dumping waste					Incineration ash
Air supplying	Anaerobic			→Aerobic	→Aerobic →Anaerobic	Anaerobic →Aerobic
Water supplying (Preparing St) (3 times in Nov.)	144ml/ week	144ml/ week + exuded water amount	Maintain Suitable Water (exuded water recirculated)	Maintain Suitable Water (exuded water recirculated)	Maintain Suitable Water (exuded water recirculated)	144ml/ week + exuded water amount
Water supplying (First Stage) Dec.14~ Jan.25 (7 weeks)	0.5 L/ week	0.5L/ week + exuded amount	0.5 L × 2 /week +exuded amount	0.5 L × 2 /week +exuded amount	0.5 L × 2 /week +exuded amount	0.5 L/week +exuded amount
Water supplying (Second Stage) Jan.26 ~ Present	0.5 L/ week	0.5 L/week (recirculate included)	0.5 L × 2 /week (recirculate included)	0.5 L × 2 /week (recirculate included)	0.5 L × 2 /week (recirculate included)	0.5 L/week (recirculate included)
Gas analysis Once/week	Generated amount, CH4, CO2, O2, N2, H2S, NH3 (GA used)					
Water property Analysis Once/week	Generated amount, pH, COD, EC, BOD, alkali level, T-N, NH4+, NO^{3-}, NO^{2-}, SO^{4-}, CL^{-}, ORP, heavy metals (for incineration ash only)					

TEST CASES AND TESTING CONDITIONS

The test cases are summarized in Table 6.

1) ater supplying (Preparation stage): (in November)

By setting the amount of water supplying to the landfill waste at 35% of the annual precipitation at the landfill site, and acknowledging the ten-year average precipitation of Nigawa region is 1218mm, the amount of water to be supplied to a column is calculated as following:

1218mm/year × 0.35 × column area (176 cm^2) / 52 weeks per year = 144 ml.

That is the amount of water to be supplied to the column once a week. The water would be infused to the waste inside the column by fix pump. Since the permeability of the landfill is $2\sim5\times10^{-5}$cm/s, the infusing rate is calculated as following:

Water infusing rate = area × permeability = 176 $cm^2\times(2\sim5\times10^{-5}cm/s)$ = 21 ~ 53 ml/min.

It was determined that the most suitable water ratio of the landfill waste is 60%, the amounts of water exuded and infused are adjusted by monitoring with hydrometer.

2) Water supplying (First stage) (Dec. 14 ~ Jan. 25):

According to the water supplying plan, the water was infused 3 times in November. However, because exudation of water was not occurred, the amount of supplying water was changed to 1 L/week instead of 144 ml/week as calculated before. The reason for doing so is explained as following:

- According to some reference data, it would require to infuse 200 liters of water to 1 ton of dumping waste to reach the most suitable water amount;
- If considering that, in order to reach that suitable water amount the infusing water amount should be expected at 2L/week since the weight of dumping waste for filling up a column is about 10 kg. However, to compromise with the calculation based on precipitation condition, the water supplying amount was set relatively at 1L/week.

- During experiment, the amount of supplying water was increased step by step. Therefore, once the modified water amount is confirmed, any variation in characteristics due to different water amount can be clarified.

3) Water supplying variation (Second stage) (Jan.26 ~ present):

Although the experiment was carried out in accordance with the water supplying plan mentioned in the First Stage, however due to a continuously increasing tendency of water exudation, re-circulation of the exuded water amount was modified from the intended value. The supplying condition from the First Stage to the Second Stage was changed on Jan. 26, 2007. Actually, in addition to the exuded water, the tap water was also used for supplying.

COLUMN TEST DEVICE INSTALLATION

Installation of column test device is outlined hereafter.

1) On the assumption that the filling material sample inside the column may break (smash) at about 20mm, the device is made of clear acrylic for enabling observation of inside.

2) The column test device consists of 3 equal column parts, each of which is 50cm in length and 15cm in diameter, able to be connected together into a 3-stage column of 1.5m high. The test material will be filled in each part of the column before connecting.

3) The column was designed strong enough with thickness of 10mm, a flat cover on the top and 3 measurement holes for sampling on the side of the column (each at the middle height of the upper, middle and lower column parts).

4) The joint between the 2 column parts is about 20mm thick, sealed up by O-ring and sealing material, and fixed by bolts at 12 positions.

5) At each measurement hole in the middle height of each column part, hydrometer is inserted for measurement.

6) A pipe of 10mm diameter is inserted from top to bottom of the column for sucking in the generated gas from all dumping waste layers, as well as supplying air to them.

7) A gas pack is equipped in order to collect the generated gas from the waste layer, as well as for the gas phase from the waste's pores to escape when sprinkling water.

8) To be able respond necessarily, the gas phase adjustment hose is set in close condition by ordinary valve.

9) Waste monitoring holes (diameter of 10mm) are set at 3 locations around the column so that measurement of temperature, water, gas etc… can be done.

10) The bottom cover of the column is designed in funnel shape so that the water extraction device can be easily clung to.

11) The bottom of the column is filled with gravel and unwoven textile on its top for good water drainage.

12) The column is wrapped from outside with paper and then with heat insulation material. When taking off these wrapping layers, the inside stabilizing condition can be observed.

The outline of column test equipment is presented in Figure 1. Photo 3 illustrates the set up of column test.

EXPERIMENTAL RESULTS

The test results obtained for the period from beginning to present (April 3rd, 2007) are reported hereafter.

1) Water inside the column

In order to clarify the water content and the water

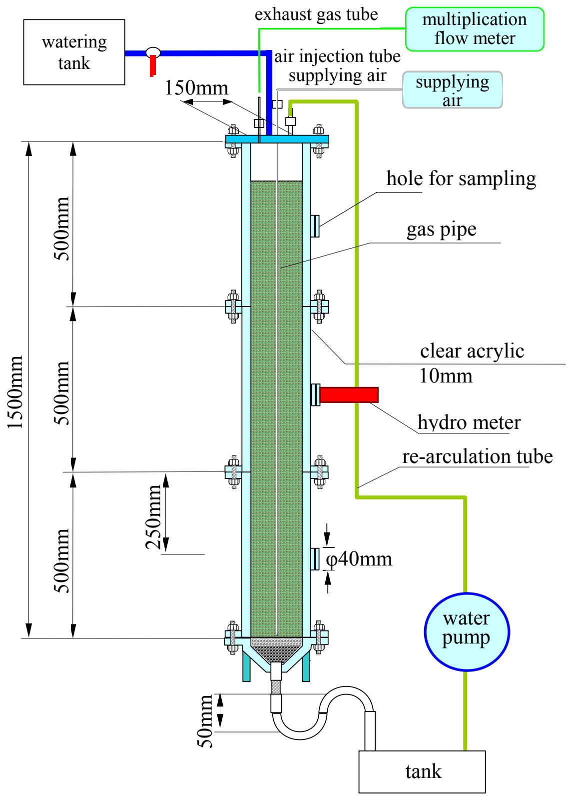

Fig 1 illustrates the set up of column test

Photo 3 set up of column test

ratio of the column, the amount of water in the filling waste was measured. Actually, for columns of case 3 and case 4, the results indicated that suitable water level has been maintained.

As shown in Table 6, the water is supplied to the columns at a rate of 0.5 liter/week for cases 1, 2 and 6, and 1 liter/week for the case 3, 4 and 5, respectively.

The exuded water was re-circulated as part of the supplying water in all cases (2 ~ 6), except for case 1. Actually, since 80cc of the exuded water was used for water quality analysis, the tap water was used instead for the inadequate amount of supplying water. Based on recording of the amounts of water supplied and exuded, variations of water ratio and water content of the tested column material are plotted in Fig.2 and Fig.3, respectively.

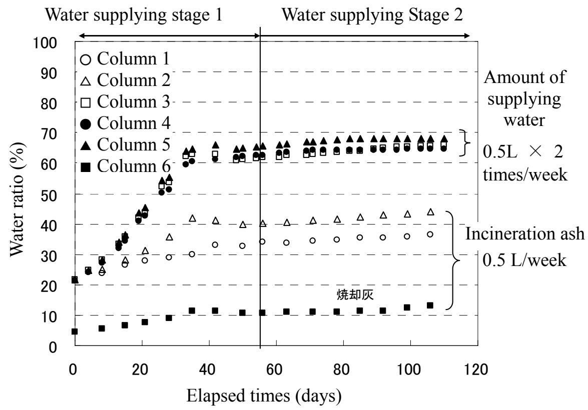

Fig 2 Column water ratio variation

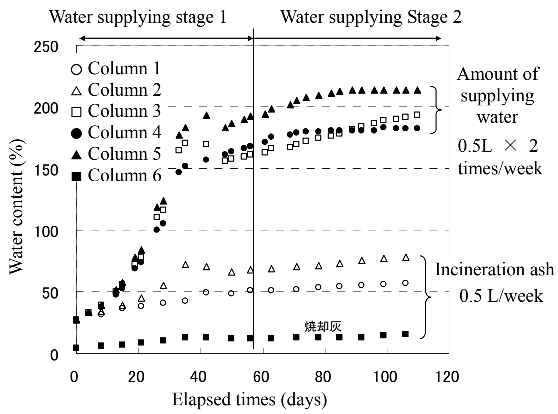

Fig 3 Column water content variation

The water conditions of the tested column material on Feb.23rd, 2007 are summarized in Table 7 for all 6 cases. According to that, for columns 1 and 2, by supplying water at 0.5 L/week, the water ratio was about 35 ~ 45%, while the water content varied from 50~80%. For columns 3, 4 and 5, by adding water at 1 L /week (actually 0.5 L twice a week), the water ratio

Table 7: Amounts of supplying water and leached out water of all column tests (Until Feb. 23rd, 2007) (Unit : mL)

Parameter	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Total amount of water supplying	6,000	8,970	24,875	24,190	25,855	8,518
Total amount of leached out water	3,228	4,865	11,995	8,815	9,920	4,729
Increase in amount of water	2,772	4,105	12,880	15,375	15.965	3,789
Initial amount of water	1984	1842	1889	2126	1889	1424
Column water amount	4,756	5,947	14,769	17,501	17,854	5,213
Initial dry weight (g)	9,143	8,490	8,708	9,796	8,708	42,125
Water ratio (%)	34.2	41.2	62.9	64.1	67.2	11.0
Water content (%)	52.0	70.0	169.6	178.7	205.0	12.4

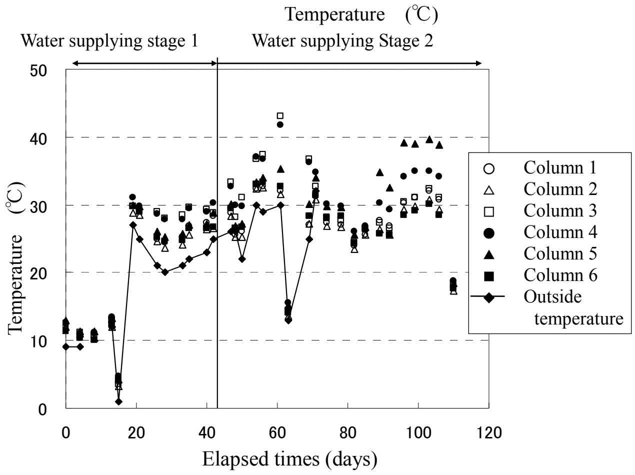

Fig 4 Column inside temperature variation

was 60-70% and the water content was as high as 180~210%. From these values and considering the initial dry unit weight of the filling material of 0.35 ~ 0.40 g/cm3, it can be said that the water had been sparkled to a quite high saturation degree. Therefore, looking at the amount of water come in and out, the amount of water inside the column is subtracted in respond to the amount of supplying water.

On the other hand, for the column filled with incineration ash in case 6, although the sprinkling water amount was 0.5 L/week, too, the water ratio and water content were as low as 13% and 15%, respectively.

2) Temperature inside the column

To clarify the micro-bio organic decomposition condition, temperature of the material layers inside the columns was measured. At the same time, the outside temperature was also measured. Variations of the inside and outside temperature are plotted in Fig.4 based on data of temperature sensor of the columns. During experiment, a warm air from air conditioner was supplied to maintain the temperature of the waste layers at 20 ~ 30℃ as normal. At the beginning of the tests (Dec.14th, 2006) the inside temperature of the columns was about 10℃ and increased to about 25 ~ 30℃ after 20 days, then gradually decreased to about 20~30℃, and again rose up to nearly 30 ~ 40℃ on the 50th day and thereafter. In all cases, the inside temperature of the column was about 0 to 10℃ higher than the outside temperature. Especially, for columns 4 and 5, such difference was even more remarkable. This phenomenon indicates that some reaction was taking place inside the column. However, since variation of the outside temperature was similar, it is considered that the inside column was more or less influenced by the outside air temperature. Also, recorded low values of temperature were due to accidental breakdown of the warm air conditioner on the days 15th, 63rd and 110th. Next time, it is intended to maintain the indoor lab temperature at more than 40℃ to investigate.

3) Exuded water quality

Water quality analysis of the exuded water was carried out to clarify the wash out and decomposition conditions. Fig. 5 illustrates the variation of pH of the exuded water. The pH value is purposely measured for evaluating up to which level the bio-reaction is possible. The general waste used for filling up column cases 1 ~

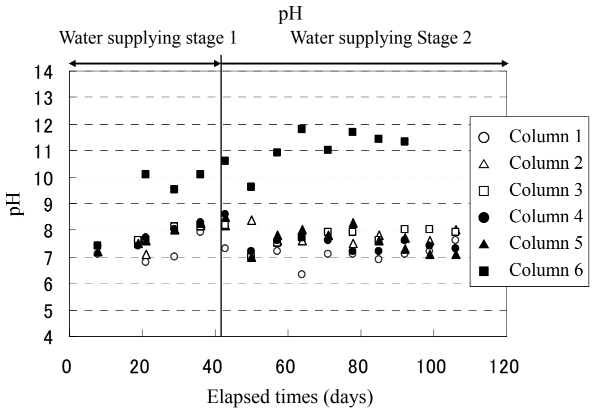

Fig 5 Variation of pH value of the exuded water

5 has the pH value of 6 ~ 8, while the incineration ash in column 6 has pH of 10 ~ 2.

Variations of COD value and BOD value of the exuded water are presented in Fig.6 and Fig.7,

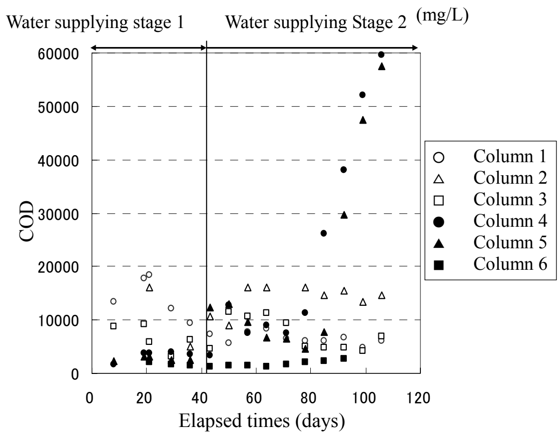

Fig 6 Variation of COD value of the exuded water

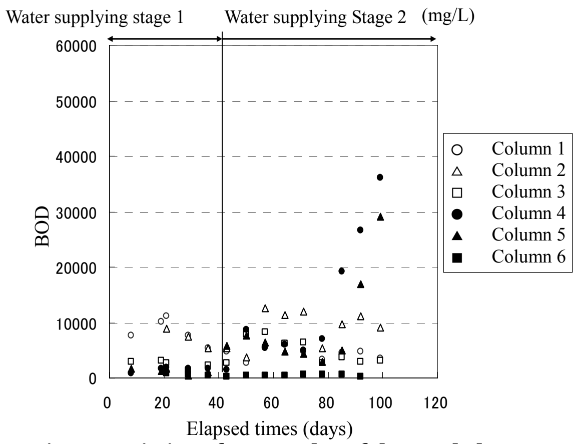

Fig 7 Variation of BOD value of the exuded water

respectively. For column 1, values of both COD and BOD were slightly decreased, while for columns 2 and 3 considerable variations were not observed. However, for columns 4 and 5 from the 80th day on, sudden increases in COD and BOD were recorded. For column 6 filled with incineration ash, both COD and BOD values were low and did not change significantly.

Variation of ammoniac nitrogen in exuded water is shown in Fig.8. For column 1, the level of NH_4^+-N in early stage was 400 mg/L, which gradually decreased thereafter. For columns 4 and 5, a sudden and remarkable increase in NH_4^+-N was observed from the 85th day on. The NH4+ - N content was lowest in the case of column 6 filled with incineration ash.

Variation of nitric nitrogen NO_2–N and nitrate nitrogen NO_3-N are shown in Fig. 9 and Fig. 10,

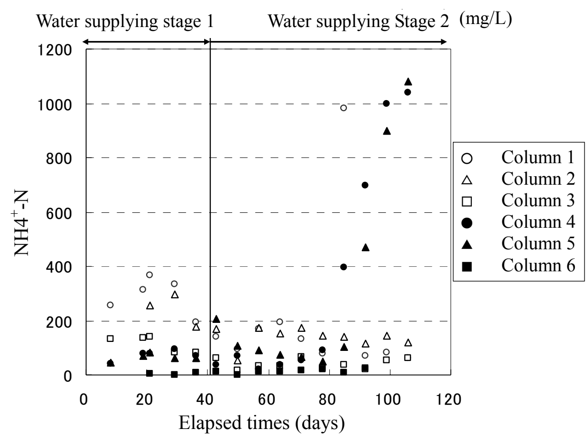

Fig 8 Variation of NH_4^+ - N of the exuded water

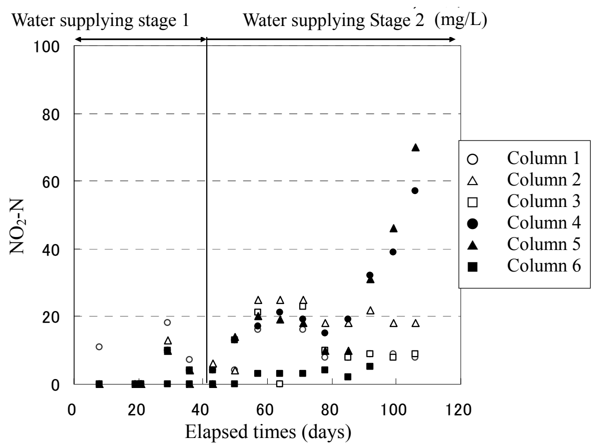

Fig 9 Variation of NO_2 - N of the exuded water

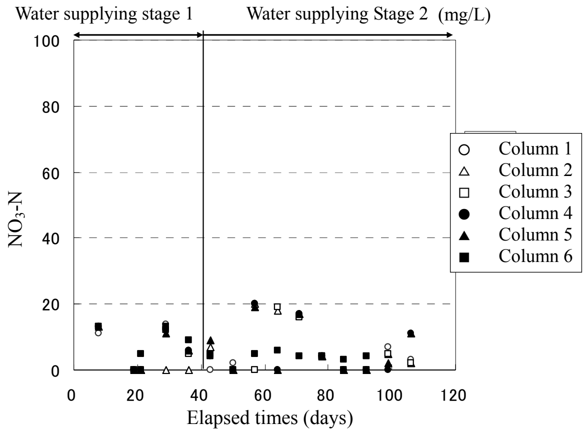

Fig 10 Variation of NO_3 - N of the exuded water

respectively. Generally, both NO_2–N and NO_3–N showed values below 30 mg/L during the tests. However, for columns 4 and 5, a significant increase in NO_2–N was found from the 85th day on. No remarkable change was occurred with the concentration of NO_3–N.

Results of analysis of heavy metals in the exuded water from column 6 filled with incineration ash are summarized in Table 8. Comparing the concentration of heavy metals at the time of making sample with that obtained from the exuded water, it was confirmed that mercury (Hg) had not been leached out with water.

Also, concentrations of cadmium (Cd) and lead (Pb) were almost zero. Concentration of chrome (Cr) demonstrated a slightly decreasing trend. Arsenic (As) started leaching out from the 64th day on. Cyanic (CN) was slightly decreased compared to the initial stage, however essential alteration was not observed. Only copper (Cu) was presented with a quite high value.

Table 8 Analysis results of heavy metals in leached out water

Measurement day		Elapsed time (days)	Hg	As	Cr	Cu	Cd	Pb	CN
When making sample		–							
	07/1/4	21	0	0.222	0.379	13.25	0.005	0	0.035
	17/1/12	29	0	0	0.243	5.484	0	0	0.021
	07/1/19	36	0	0	0.212	6.516	0	0	0.016
	07/1/26	43	0	0	0.212	6.516	0	0	0.015
	07/2/2	50	0	0	0.222	2.527	0	0	0.015
	07/2/9	57	0	0	0.232	6.081	0	0	0.016
	07/2/16	64	0	0.052	0.18	5.798	0	0	0.015
	07/2/23	71	0	0.081	0.195	7.336	0	0	0.013
	07/3/2	78	0	0.087	0.172	13.17	0	0	0.015
	07/3/9	85	0	0.092	0.163	11.87	0	0	0.014
	07/3/16	92	0	0.056	0.135	7.821	0	0	0.012
	07/3/23	99	No leached out water						
	07/3/30	106	– (Too little amount of leached out water)						
Standard value of discharge water			0.005	0.1	0.5	3	0.1	0.1	1

4) Generated gas amount

Variation of the generated gas amount is shown in Fig. 11. After 80 days, the amount of gas generated from column 3 was considerable, however, for the other columns it was quite little. Therefore, investigating on countermeasures for early generating gas is needed in the next time.

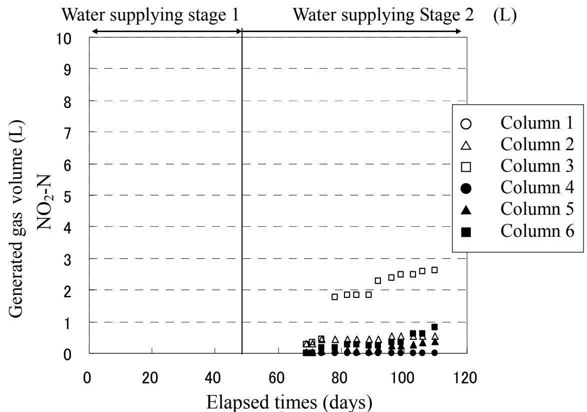

Fig 11 Variation of generated gas amount

DISCUSSIONS ON TEST RESULTS

From the test results of a period of 120 days since the start of experiment, following conclusions can be drawn:

- Tested material components: for the general waste used in columns tests 1~ 5, about 97% of the substance was combustible (vinyl, paper, fiber, wood, raw material) and 3% was incombustible (glass, metals and other) substances. For that general waste, the average component compositions including water, ahs and combustible were 18%, 17%, and 65%, respectively. For the incineration ash used in column 6, the component composition was characterized by 3% water, 95% ash and incinerated weight reduction 2%.

- Water supplying: 3 regimes of water supplying were deployed: 0.5L/week, 0.5L/week + exuded water, 0.5L × 2 times/week + exuded water. With increasing the amount of water circulation, the water ratio increased gradually and monotonously during the 6-week period of First stage water supplying. After that period, due to using mainly the exuded water for supplying, only a minor increase in the water ratio was maintained.
- Temperature: after setting up the test, temperature outside the column was about 10℃ 20 days. After that it was maintained at 20~30℃. Although inside the column, temperature was about 0 ~ 10℃ higher than that outside, however, it can be considered that such a difference in temperature was not due to activity of micro-bioorganic at this stage. The inside column temperature increased up to 35 ~ 40℃ from the 85th day on was seen for columns 4 and 5.
- The pH value: for columns 1 ~ 5 with general waste, the pH value was in the range of 7 ~ 8. On the other hand, for column 6 with incineration ash, the pH value was about 10, but increased to 11 ~ 12 at present.
- BOD and COD values: during 6 weeks of increasing water circulation (Water supplying First stage) decreasing tendencies of BOD and COD values were found. After that, as the exuded water had been involved as a part of the supplying water (Water supplying Second stage), both of BOD and COD values indicated increasing trend. Especially, for columns 4 and 5, the increase was remarkable.
- Ammoniac nitrogen: during 6 weeks of circulating water (Water supplying First stage) the NH_4^+-N showed a slightly decreasing tendency. However, from the 85th day on, a significant increase in concentration of NH_4^+-N was seen for columns 4 and 5, while no considerable change was observed for the other columns.
- Nitric nitrogen: from the 85th day on the concentration of NO_2–N in the exuded water notably increased for columns 4 and 5.
- Heavy metals: from the results of element analysis of heavy metals in the water exuded from incineration ash, rather high concentration was found for copper (Cu) only.
- Generation of methane gas: Except for the column 3 where the gas was started generating from the 80th day on, for the other columns the generation of gas was almost not observed.

RECOMMENDATIONS

Although expecting that providing an anaerobic condition to the landfill waste would make the methane gas effectively generated, however, for a period of 120 days of the experiment the gas generation has almost not been seen yet. Therefore, it is recommended that next study should focus on the problem of early generation of the methane gas, for which the column conditions and so on should be examined again.