# Characteristic and Mechanism of Semi-Aerobic Landfill on Stabilization of Solid Waste

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**Abstract**

The details of a semi-aerobic landfill type are described and compared with an aerobic landfill type, particularly related to the characteristics of the solid waste stabilization and the stabilization mechanism. Semi-aerobic landfill is an attempt to lay the leachate collection pipe, comprising the perforated main and branch pipes and gravel, at the bottom of the landfill to discharge leachate out of the landfill as quickly as possible. This prevents leachate from penetrating into the ground water by removing leachate remaining from the bottom of the landfill. Also, oxygen in air is led into the landfill through the leachate collection pipe by heat convection resulting from differences between the inner temperature and outside air temperature. Comparative studies of the decomposition characteristics of the pollutant components in the semi-aerobic and anaerobic landfill types have been conducted by using two types of large lysimeters. Clarified differences between landfill types are as follows: (1) biodegradation of semi-aerobic type was mainly gasification dominated by carbon dioxide, (2) production decomposition of the BOD and T-N components in the seepage water in the bottom layer close to the leachate collection pipe of the semi-aerobic lysimeter was clearly evident, and (3) elution of the pollutant components not in the vicinity of the leachate collection pipe was more remarkable than the anaerobic landfill, suggesting that decomposition of the waste itself is accelerated.

**Keywords** – municipal solid waste, landfill, semi-aerobic, anaerobic, landfill type, pollutant, purification, stabilization, biodegradation, lysimeter, leachate

## 1. Introduction

The function of a landfill site lies in appropriate storing solid waste and enhancing stabilization of landfilled solid waste. The stabilization of landfilled solid waste extremely depends on factors such as a quality of solid waste, a landfill type, a method of landfilling, and weather conditions at the location of a landfill. The stabilization of a semi-aerobic landfill type adopted in Japan was described with comparing the stabilization of a semi-aerobic landfill and an aerobic landfill.

Semi-aerobic landfill is an attempt to lay the leachate collection pipe, comprising the perforated main and branch pipes and gravel, at the bottom of the landfill to discharge leachate out of the landfill as quickly as possible. This prevents leachate from infiltrating into the ground water by draining leachate remaining from the bottom of the landfill. Also, oxygen in air is led into the landfill through the leachate collection pipe by heat convection resulting from differences between the inner temperature and outside air temperature (Hanashima et al. 1981 a). The leachate collection pipe of a semi-aerobic landfill has the following effects: acceleration of leachate discharge ensures expanding aerobic atmosphere and improves activities of aerobic bacteria, decomposition of solid waste, and leachate quality.

Three experiments were conducted in this study by using large lysimeters simulated a semi-aerobic landfill and an anaerobic landfill. The first of all, the mass balance of organic compound for the lysimeter was calculated to clarify the differences of biodegradation process (i.e., gasification and liquefaction) between a semi-aerobic landfill type and an aerobic landfill type. Next, the leachate quality and gas composition in the solid waste were found out to make clear the differences of mechanism on stabilization of solid waste between two types of landfill.

## 2. Engineering Development and Structure of Semi-Aerobic Landfill (Hanashima et al. 1981 a)

### 2.1 Engineering Development

The research on landfill technology in Japan was started by Professor Masataka Hanashima at Fukuoka University in 1966. At this period, the amount of generated municipal solid waste was increasing with the growing of Japanese economy year by year. Main component of municipal solid waste was food waste without intermediate treatment such as incineration and landfilled solid waste included much organic matters. As a natural consequence, the rapid stabilization of landfilled solid waste and the improvement of leachate quality became big social issues in 1960's of Japan.

Professor Hanashima attempted to inject air ($O_2$) in landfilled solid waste from the bottom of a landfill in order to enhance the stabilization of solid waste. This novel method for the rapid landfill stabilization showed the effective results, but it consumed much amount of power to send air in a landfill and was recognized uneconomical. After the many experiments, a new landfill type, where air is supplied spontaneously through the leachate collection pipe that has bigger diameter than the former collection pipe, was developed. The role of leachate collection pipe at this new landfill type is intake of air ($O_2$) as well as collection of leachate. The mechanism of this air intake cleared by Professor Hanashima is that heat convection resulting from differences between the inner temperature and outside temperature leads air into a landfill through the leachate collection pipe.

Now, this type of a landfill is called Semi-aerobic Landfill Type in Japan. The first semi-aerobic landfill was constructed by Fukuoka City in 1975. After ascertaining its positive effect on the environment, the Ministry of Health and Welfare has adopted the Fukuoka Method through Japan, being a recommended method in the Final Waste Disposal Guidelines Issued. The development of semi-aerobic landfill provided the impetus for a range of research and academic activities in landfill technology, which until then had not been systematically organized.

## 2.2 Structure of Semi-Aerobic Landfill

Since the self-stabilization capacity of the landfill was found out in the latter 1960s, study has been made on the structure of the landfill in an effort to make an effective use of this capacity in Japan. Amid such study efforts, Masataka Hanashima of Fukuoka University et al. established the concept of "Landfill type"— "If the landfill is aerobic, it can be an effective purification area for solid waste". Namely, the landfill is not only an open dumping area of municipal solid waste; it is required to serve as a purification area for solid waste to ensure acceleration of stabilization. Based on this concept, a new landfill type of semi-aerobic landfill, which actively degrade and decompose the solid waste was proposed. At the same time, classification of the type (the structure) was made (Hanashima et al. 1981 b). It has been clarified that quality and amount of leachate and gas depend on the landfill type. Fig. 1 shows classification of the landfill. The landfill is classified into five landfill types, with attention focused on the envi□

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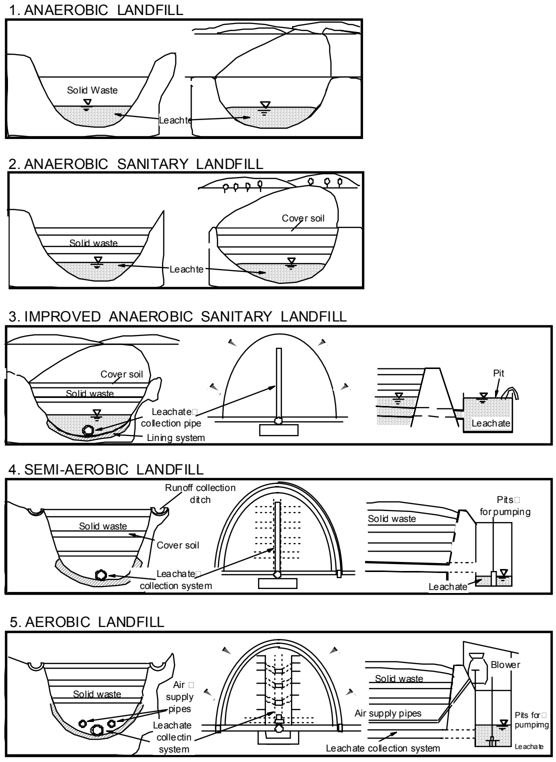


Fig. 1. Classification of landfill types.

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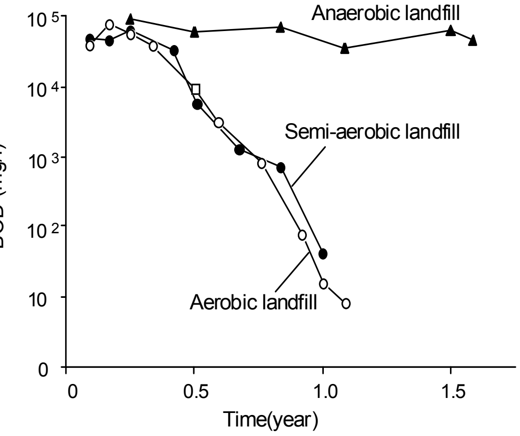


Fig. 2. Relationship between landfill type and leachate quality□
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é@ÿ□□Uªlows: (a) aerobic landfill contains a greater number of bacteria in the solid waste layer than anaerobic landfill; (b) a great number of sporogenic bacteria are found in the solid waste layer of the aerobic landfill, stable decomposition is carried out without being affected by environmental changes; (c) bacteria in the aerobic landfill are very active in cellulose degradation; and (d) organic acid is produced as a result of decomposition of solid waste in the anaerobic landfill, and inhibits bacterial growth, resulting in slow stabilization at the landfill. Therefore, creating aerobic atmosphere in the solid waste layer is important to accelerate landfill stabilization.

### 2.3 Role of Leachate Collection and Discharge Facility on Semi-Aerobic Landfill

Semi-aerobic landfill is an attempt to lay the leachate collection pipe, comprising the perforated pipe and gravel, at the bottom of the landfill to discharge leachate out of the landfill as quickly as possible. This prevents leachate from penetrating into the original ground without allowing leachate remaining in the solid waste layer, and takes air into the solid waste layer through the collection pipe, thereby purifying leachate in the solid waste layer before collection. That is, semi-aerobic landfill has the following function: temperature in the landfill is raised by heat of biodegradation in the solid waste, and air (oxygen) is led into the landfill through the leachate collection pipe by heat convection resulting from differences between the inner temperature and outside air temperature (Hanashima et al. 1981 a). Its concept is illustrated in Fig. 3. This leachate collection pipe has the following effects: (a) acceleration of leachate discharge prevents leachate from remaining in the solid waste layer, and ensures easier penetration of air, thereby expanding aerobic atmosphere in the solid waste layer; (b) expanded aerobic atmosphere improves activities of aerobic bacteria and accelerates decomposition of solid waste; (c) a combined use of the perforated pipe and gravel improves leachate quality; and (d) clogging of the perforated collection pipe is reduced.

The collection pipe comprises a perforated pipe and gravel covering the pipe. Larger diameters of the collection pipe and the covering gravel arc preferred. Although the diameter of the leachate collection pipe

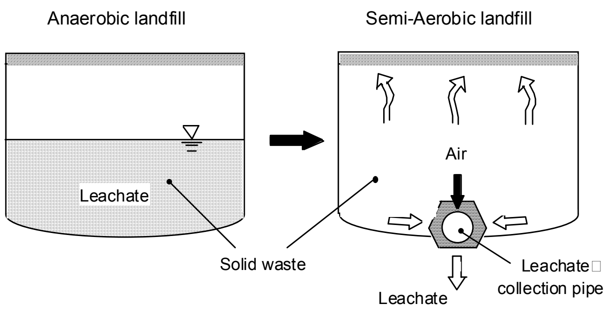


Fig. 3. Role of leachate collection pipe.

varies according to rainfall volume and topographic features at the site, the standard diameter in Japan is 450 to 600 mm. Furthermore, the branch pipe of the leachate collection pipe frequently has a diameter of about 250 mm. Covering the surface of the gravel material with sands or unwoven fabrics is not recommended since it may cause clogging.

### 3. Comparison of Solid Waste Stabilization between Semi-Aerobic Landfill and Anaerobic Landfill (Matsufuji et al. 1993 and 1998)

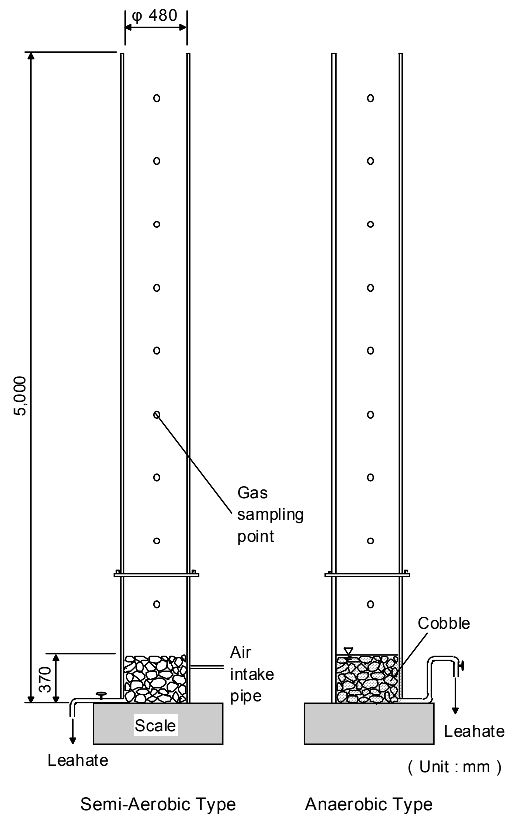


Fig. 4. Two Types of the Lysimeters used for the experiment.

The apparatus used for this study consisted of two lysimeters made of plastic with 485 mm in inner diameter and 5.0 m in height is shown in Fig. 4. One lysimeter was simulated a semi-aerobic type of landfill with air inflow naturally from the hole at the bottom. The other lysimeter was simulated an anaerobic type of landfill without the air inflow from the bottom. The two lysimeters were filled with garbage under the conditions show in Table 1. These lysimeters were left on large scales and the decrease in weight due to evaporation of water and gas generation from solid wastes had been weighted continuously. As the same time, the amount of water evaporation and gas generation were measured by collecting into the absorbents (magnesium perchlorate for water vapor and ascarite for carbon dioxide) as shown in Fig.5.

Fig. 6 shows the changes in BOD and pH with time. Based on the pattern of the changes in BOD and pH, the biodegradation processes for the semi-aerobic and anaerobic landfill types were divided into 3 and 2 phases, respectively. Fig. 7 shows the bimonthly change of evaporation residue in leachate in the two landfill types. The amount of evaporation residue in leachate at Phase-1 in both landfills types was large. However, at Phase-2 evaporation residue at Phase-1 in the anaerobic type was about 2 times larger than that in the semi-aerobic type and the period of Phase-1 in the anaerobic type was 12 months longer than that in the semi-aerobic one. Fig. 8 shows the amount of gases

Table 1. Landfill condition.

| Item | Lysimeter A ( Semi-aerobic ) | Lysimeter B ( Anaerobic ) |
|---|---|---|
| Composition (% dry base) | | |
| Garbage | 27.8 | 27.8 |
| Plastics | 14.1 | 14.1 |
| Incombustibles | 4.8 | 4.8 |
| Wet weight (kg) | 582.0 | 582.0 |
| Moisture content (%) | 65.0 | 65.0 |
| Dry weight (kg) | 203.9 | 203.9 |
| Organic matter (kg) * | 139.6 | 139.6 |

* Ignitio loss , 600 degrees

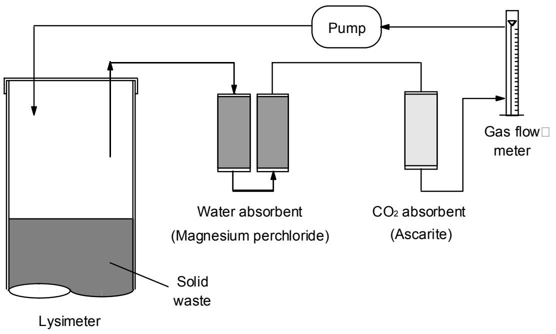


Fig. 5. Measuring apparatus of gas and vapor generation amount.

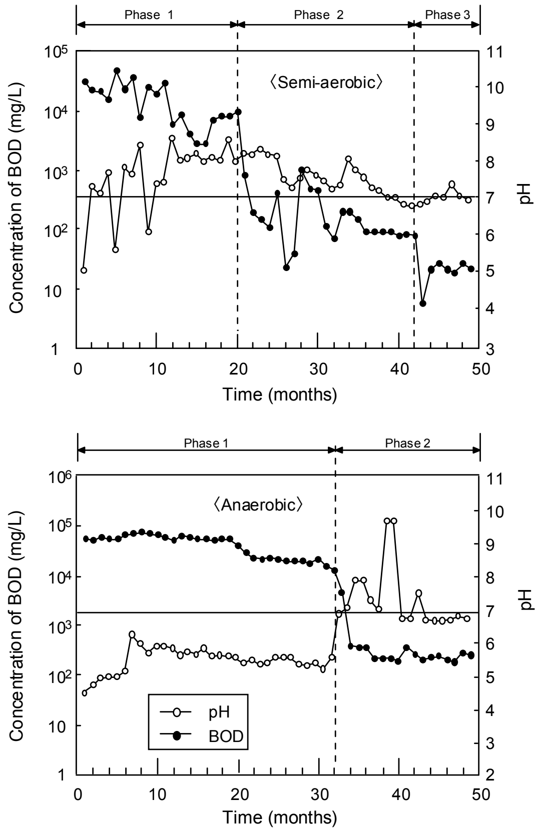


Fig. 6. Monthly change in pH and BOD concentration in leachate from two types of lysimeters.

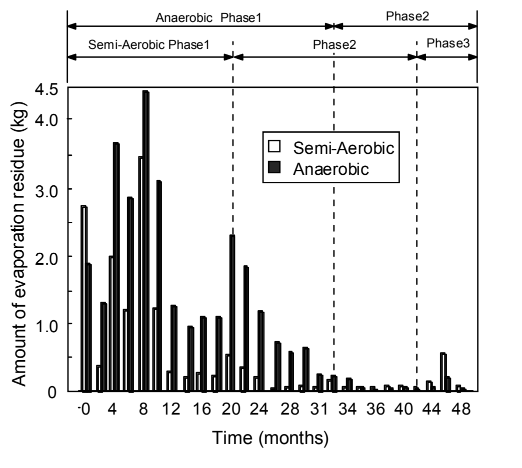


Fig. 7. Bimonthly change in the amount of evaporation residue leaching from each lysimeter.

generated from the semi-aerobic and the anaerobic types. At Phase-1, the amount gases generated from the semi-aerobic type were approximately 200 g/day in summer (12 months) and 50 g/day in winter (18 months). After that, at Phases-2 and Phases-3, they were increased to 250 g/day in summer (32 months) and 50 g/day in winter (38 months). On the other hand, that from the anaerobic type at Phase-1 was about 50 g/day in summer (12 months) and 10 g/day in winter (18 months). The amount of generated gases as Phase-2 was about 2 times larger than at Phase-1 and was less than two thirds of that from the semi-aerobic type at Phase-2.

Fig. 9 shows the cumulative amount of gases and contaminants (measured by the evaporation residue) which flow out together with the leachates for four years. As the results, the total amount of generated gases and leachated contaminants (total loss) with 66.3 kg for the semi-aerobic type was larger than the total loss with 53.2 kg for the anaerobic type. The gasification ratio (the ratio of total loss against the

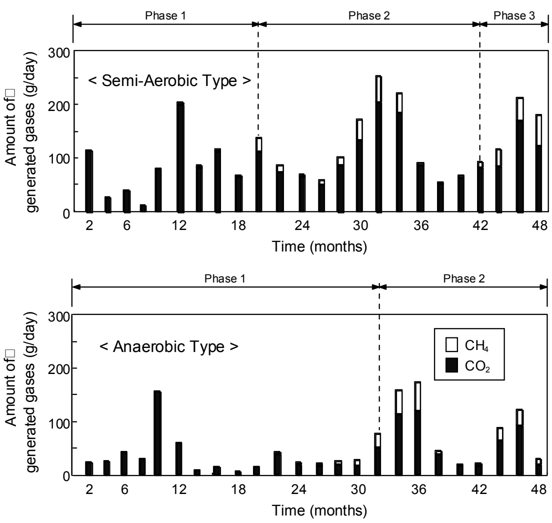


Fig. 8. Bimonthly change in the amount of generated gases from each lysimeter.

organic matter in the solid waste, see in Table 1) of the semi-aerobic type and the anaerobic type is 37 % and 15 % respectively. The ratio of generated gases to leached contaminants was 8 : 2 for the semi-aerobic and 4 : 6 for the anaerobic. The contaminant load of leachate in the semi-aerobic landfill type can be

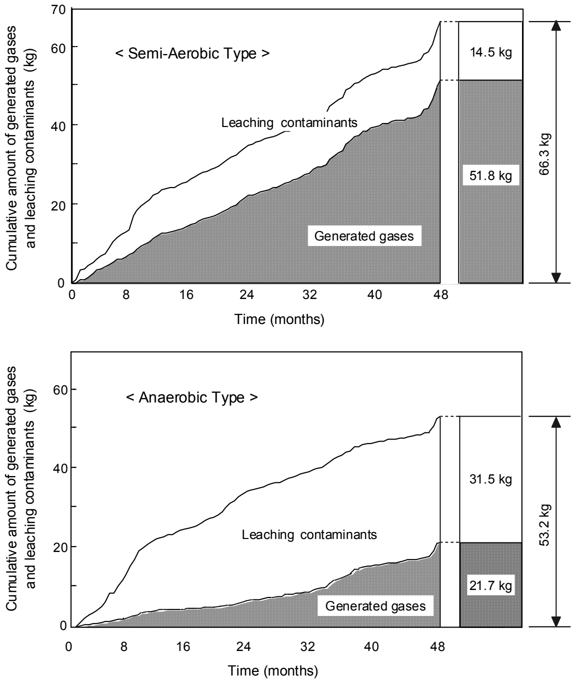


Fig. 9. Cumulative amount of generated gases and leaching contaminants.

reduced compared to the anaerobic type. The results suggest that the semi-aerobic landfill type should give greater advantages for environmental protection.

## 4. Mechanism of Semi-aerobic Landfill on Stabilization of Solid Waste (Shimaoka et al. 1997 and 2000)

Creating aerobic atmosphere in the anaerobic landfill makes it possible to control generation of methane gas from the landfill and to reduce the amount of pollutants in leachate. So the semi-aerobic landfill ranked between the anaerobic and aerobic landfills is used in Japan. The purification mechanism of this semi-aerobic landfill is being clarified by the study made on the changes in the quality of pollutants in the solid waste layer (Lee et al. 1993 and 1994). Regarding the differences between the semi-aerobic and anaerobic landfills, however, only gas generation and leachate characteristics have been made clear, as mentioned earlier. So we have conducted experiments to find out the leachate quality and gas composition in the solid waste layer, using landfill lysimeters for the semi-aerobic and anaerobic landfills, and to clarify the purification mechanism of the anaerobic landfill, thereby demonstrating the superiority of the semi-aerobic landfill.

Fig. 10 shows these experiments which utilized large-sized landfill lysimeters simulating the

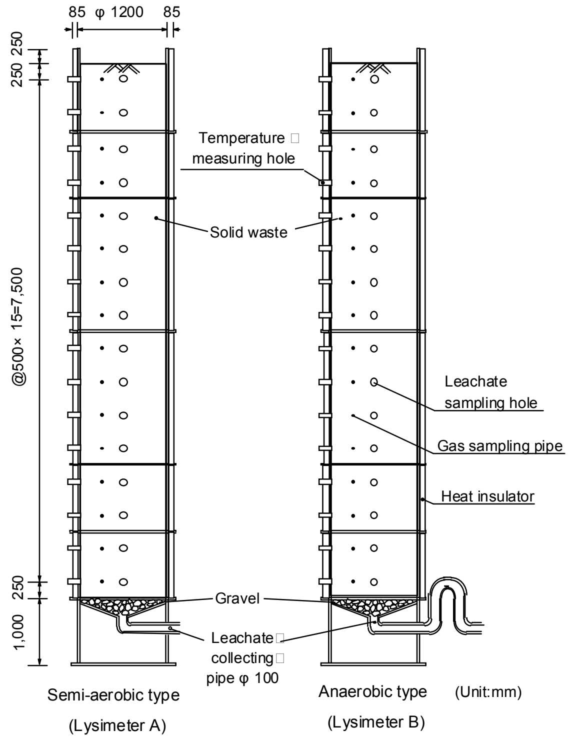


Fig. 10. Large-size landfill lysimeters.

semi-aerobic landfill type (hereinafter referred to as "semi-aerobic lysimeter A") and anaerobic landfill type (hereinafter referred to as "anaerobic lysimeter B"). They were filled with regulated waste (shredded solid waste: incineration residue: municipal solid waste compost = 7: 1.5: 1.5 by weight). The landfill lysimeters were full-size replicas of actual sites; the amount of landfilled solid waste was 9.5 tons per lysimeter, and the solid waste layer was 8.0 m high. Temperature measuring holes and gas intake holes, leachate intake valves, and observation holes were provided at intervals of 50 cm on the sidewall. In the experiment, we sampled and analyzed seepage water (leachate in the solid waste layer), leachate (exiting lysimeter), and gas on a periodic basis.

Fig. 11 shows temporal changes in the quality of leachate from the semi-aerobic and anaerobic lysimeters. In the initial stage of the experiment, concentration in the anaerobic lysimeter was higher in both BOD and T-N. The relationship between the landfill type and leachate quality was also observed in this experiment. This trend was observed when one year and a half have passed. Fig. 12 shows the temporal change of the cumulative release of the BOD and T-N components. The release of both components was greater in the anaerobic lysimeter than in the semi-aerobic lysimeter; both components exit in the leachate, without being decomposed in the solid waste layer. Furthermore, a great difference in the BOD

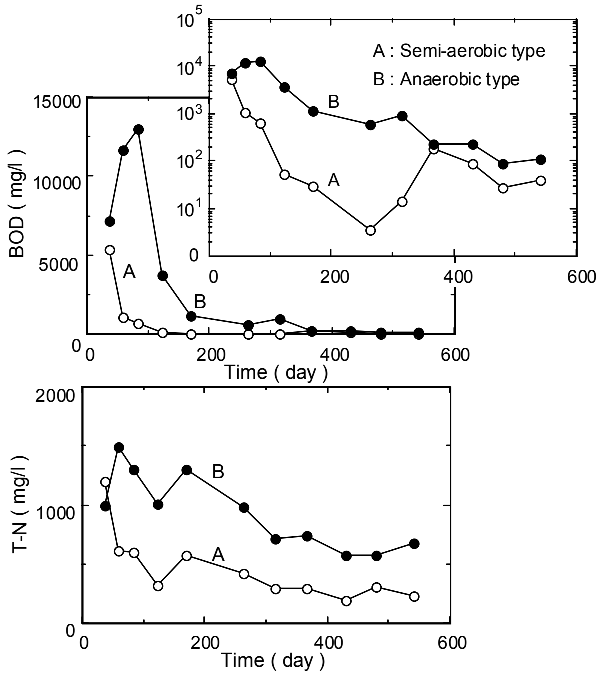


Fig. 11. Change of leachate quality with time.

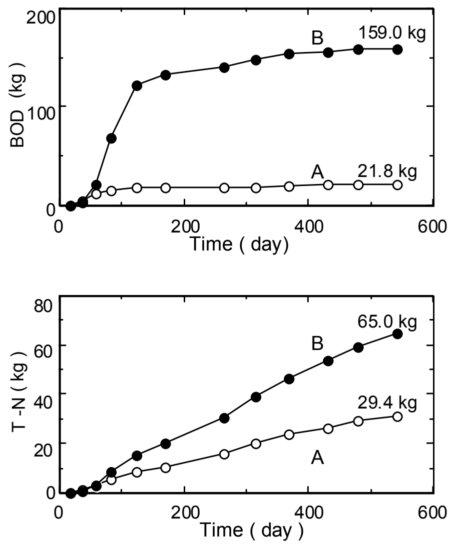


Fig. 12. Cumulative release.

component leakage between two lysimeters was observed in the initial stage (6 months). By contrast, the cumulative leakage of the T-N component showed an almost straight line increase over time. On the 541st day, the cumulative leakage of the anaerobic lysimeter was about twice that of the semi-aerobic lysimeter.

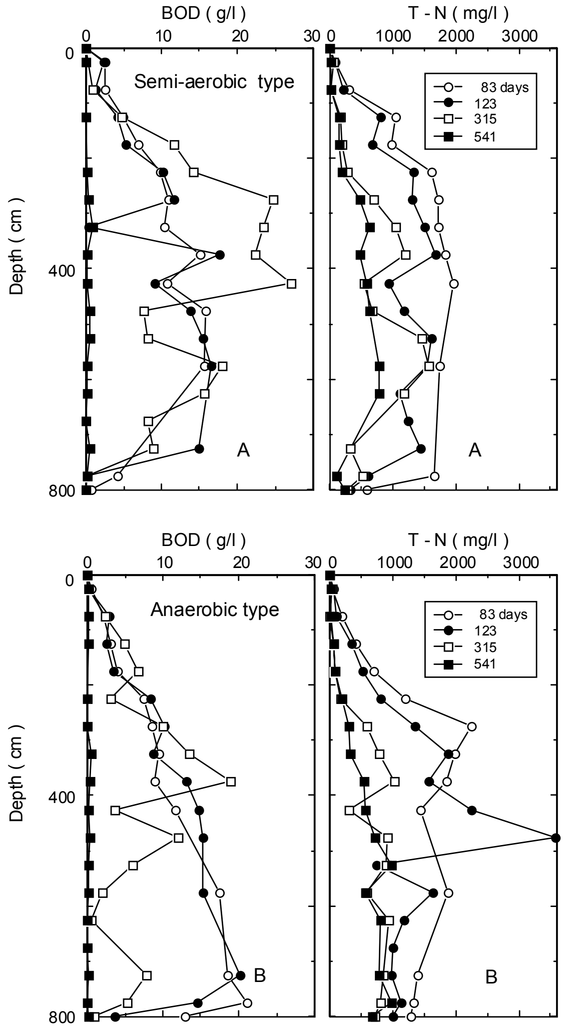


Fig. 13. Changes of the leachate quality with time.

Let us observe the change of the leachate quality with time as shown in Fig. 13 in order to see the difference of the concentration of the BOD and T-N components in the leachate. First of all, there was a sharp decline in the BOD concentration on the bottom layer of the semi-aerobic lysimeter (6 to 8 meters deep). This trend can be seen already on the 83rd day when BOD concentration distribution was obtained for the first time. The sharp decline in the BOD concentration at the bottom is considered to be caused by aerobic decomposition due to air (oxygen). It can be seen that the decomposition was active in earlier stage. On the other hand, for the initial period of about six months, the BOD concentration of the anaerobic lysimeter increases with depth almost in a straight line from the surface layer to the vicinity of the gravel. Decline in concentration can be only in the narrow area at the bottom. This decline in concentration was smaller than that of the semi-aerobic lysimeter for the same period of time, and is considered to be caused by the anaerobic decomposition of the BOD component. Thus, a high BOD was observed in the leachate of the anaerobic lysimeter. However, after the lapse of about six months, the distribution of BOD concentration in the anaerobic lysimeter exhibited a pattern in which increase and decrease of concentration are repeated in the direction of depth, similar to the case of the semi-aerobic lysimeter. There were no such remarkable differences in leachate qualities between two lysimeters as were observed for the initial period of six months. This is considered to be the reason why conspicuous differences in the BOD concentration of leachate and BOD cumulative leakage have been caused between the semi-aerobic lysimeter and anaerobic lysimeter in the initial period of experiment (see Fig. 12).

The T-N concentration distribution exhibited conspicuous differences at the bottom between the semi-aerobic lysimeter and anaerobic lysimeter. Fig. 14 shows the concentration distributions of $NH_4^+$-N and $NO_x^-$-N (= $NO_2^-$-N + $NO_3^-$-N) on the 431st day as an example. At the bottom of the semi-aerobic lysimeter, there was an increase of $NO_x^-$-N and a sudden decrease of $NH_4^+$-N at the same time. Decrease of $NO_x^-$-N was observed in the limited area deeper than

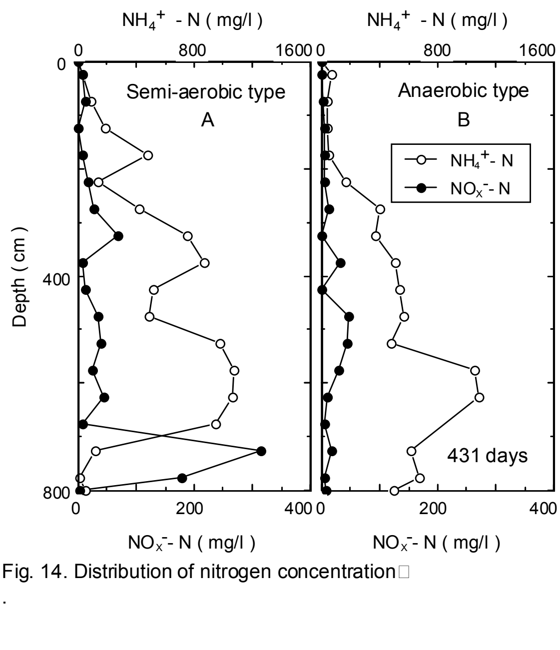


Fig. 14. Distribution of nitrogen concentration

that, and denitrification is accomplished by decrease of T-N. On the other hand, the anaerobic lysimeter had no air flowing from the leachate collection pipe, so nitrification was not observed at the bottom, and the T-N leaks out at a high concentration without being decreased.

Fig. 15 shows the distributions of gases concentration on the two landfill types. In the semi-aerobic lysimeter, the remarkable consumption of oxygen ($O_2$) was observed at the bottom near a leachate collection pipe as well as at the surface of the lysimeter. The region where the $O_2$ shows the high concentration at the bottom was extended with the progress of solid waste degradation. There were no conspicuous differences between the carbon dioxide ($CO_2$) distributions of two lysimeters. The increase of $CO_2$ concentrations from the bottom to the surface in two types of lysimeters was shown in the initial period of experiment (on 85 and 138 days). The $CH_4$ concentration in the anaerobic lysimeter was higher than the concentration in the semi-aerobic, especially at the bottom of the anaerobic lysimeter.

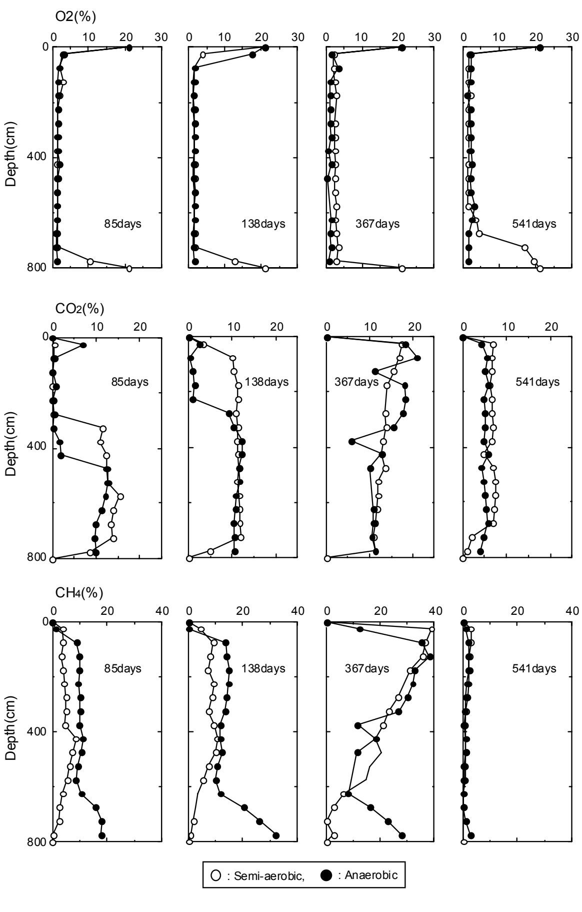


FIg. 15. Distribution of gases concentration.

Fig. 16 shows the depth-wise cumulative amounts of changes ($= \varepsilon_L \partial C/\partial t + U \partial C/\partial x$, where $\varepsilon_L$: water content by volume, C: seepage water concentration, U: seepage speed, t: time, x: depth) of BOD and T-N components on the solid waste layers (a total of 17 layers) between sampling points over the experimental period obtained from seepage water concentration. The BOD component exhibited an increase in the cumulative amount of the change at a depth of about 3 meters independently of the landfill type. Elution (solubility of the pollutant into seepage water) was more remarkable than decomposition (gasification from the seepage water of the pollutant). Furthermore, there was a decrease in the cumulative amount of the change at the bottom, and this was more conspicuous in the semi-aerobic lysimeter than in the anaerobic lysimeter; it suggests active decomposition taking place. The amount of the change in the T-N component increased at a depth of 3 to 4 meters, giving a remarkable elution from the solid waste. At the bottom, there was a decrease in the amount of the change in the semi-aerobic lysimeter because of above-mentioned differences between denitrification and nitrification caused by the landfill type (presence or absence of oxygen flowing from the leachate collection pipe). However, this was not observed in the anaerobic lysimeter. Lastly, let us see the magnitude of the cumulative amount of the change of the BOD and T-N components between landfill types in the direction of depth. In the solid waste layer, except for the bottom layer (6 to 8 meters deep), the cumulative amount of

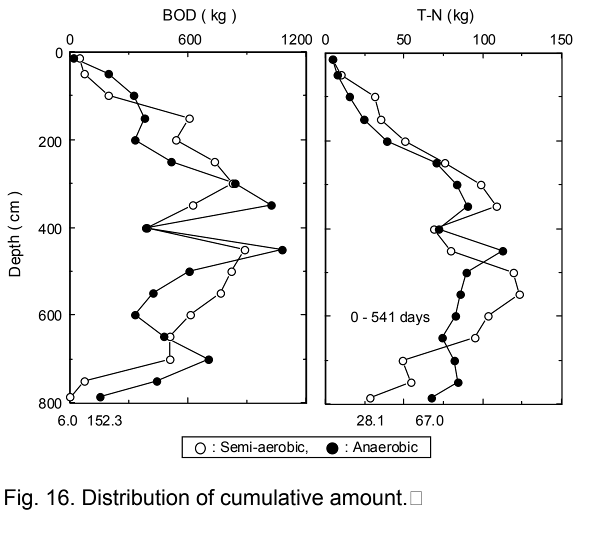


Fig. 16. Distribution of cumulative amount.

the change was greater in the semi-aerobic lysimeter than that in the anaerobic lysimeter; however, the cumulative mass resulting from leachate was greater in the anaerobic lysimeter than that in the semi-aerobic lysimeter (see Fig. 12). This leads to the conclusion that, in the solid waste layer except for the bottom layer, elution of the pollutant into the seepage water is more remarkable in the semi-aerobic lysimeter than in the anaerobic lysimeter.

## 5. Conclusions

The engineering development and structure of semi-aerobic landfill was mentioned, and the characteristic and mechanism of semi-aerobic landfill on stabilization of solid waste were described, based on the information of long term experiments utilizing large size lysimeters simulated a semi-aerobic type and an anaerobic type of landfills. The following results with regards to the stabilization of solid waste can be listed.

(1) The biodegradation process of the semi-aerobic and the anaerobic landfill type was divided into 3 and 2 phases in the period of four years. The biodegradation of semi-aerobic type was mainly gasification dominated by carbon dioxide production. The gasification rate of the semi-aerobic type and the anaerobic type was 37 % and 15 % for a four-year period. In the semi-aerobic landfill type, the contamination load of leachate was reduced compared to the anaerobic type.

(2) The differences in BOD leakage resulting from leachate between two types of landfills occurred at an earlier stage (in the initial period of about six months) after landfilling of the solid waste. The decomposition of the BOD in the seepage water in the bottom layer close to the leachate collection pipe of the semi-aerobic landfill type was more conspicuous than that in the anaerobic landfill type. In the semi-aerobic landfill type, the T-N at the bottom was actively decomposed by nitrification and denitrification. However, oxygen was not present at the bottom layer of the anaerobic landfill type, therefore, nitrification did not occur. This produces leachate containing the highly concentrated T-N. Except at the bottom layer, the cumulative amount of the change in the BOD was greater in the semi-aerobic landfill type. Elution of the pollutant component in the solid waste of the semi-aerobic landfill type was considered to be more remarkable than the anaerobic landfill type, suggesting that decomposition of the waste itself is conspicuous.

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**Caption**

Table 1. Landfilling condition.

Fig. 1. Classification of landfill types.

Fig. 2. Relationship between landfill type and leachate quality.

Fig. 3. Role of leachate collection pipe.

Fig. 4. Two types of the lysimeters used for the experiment.

Fig. 5. Measuring apparatus of gas and vapor generation amount.

Fig. 6. Monthly change in pH and BOD concentration in leachate from two types of lysimeters.

Fig. 7. Bimonthly change in the amount of evaporation residue leaching from each lysimeter.

Fig. 8. Bimonthly change in the amount of generated gases from each lysimeter.

Fig. 9. Cumulative amount of generated gases and leaching contaminants.

Fig. 10. Large-size landfill lysimeters.

Fig. 11. Change of leachate quality with time.

Fig. 12. Cumulative release.

Fig. 13. Changes of the leachate quality with time.

Fig. 14. Distribution of nitrogen concentration.

Fig. 15. Distribution of gases concentration.

Fig. 16. Distribution of cumulative amount.