京都大学防災研究所年報 第43号 B-2 平成12年4月
Annuals of Disas. Prev. Res. Inst., Kyoto Univ., No. 43 B-2, 2000

# Effect of Landfill Cover System on Water Interception

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## Synopsis

The purpose of landfill cover system is to minimize the infiltration of rainfall into the waste layer using a low hydraulic conductivity barrier layer. In this paper, the application of sludge materials to the barrier layer of cover system through laboratory study has been evaluated. The rainfall water interception effect in a cover system that applied to the barrier layer using sludge materials has been verified using the water balance model results. Further, the rainfall interception effect of the proposed cover system has been studied using a barrier layer of 10 cm thickness and hydraulic conductivity, $1 \times 10^{-7}$ cm/s for various climatic environmental conditions in Japan

**Keywords**: landfill; cover system; rainfall water interception effect; hydraulic, conductivity; sludge

## 1. Introduction

In waste management practice, the primary purpose of landfill cover system is to reduce the leachate generation percolating through the waste during the inactive (postclosure) period. The estimation of leachate production after the closure of landfill is an important task for landfill designers, which ultimately depends on the percolation rate of final cover system (Khire et al. 1997). Several investigators carried out an extensive analysis on the water balance of landfill final cap systems (Benson et al. 1994; Chiu and Shackelford 1998). Evatranspiration and lateral drainage are the two dominant parameters to be considered in the water balance analysis, and the cover system should be designed to maximize the above mentioned factors. Properly designed cover system can limit the amount of percolating water below the root zone, which can protect the groundwater as efficiently as a traditional barrier cap. Hydrologic water balance calculations should be used to estimate the amount of supplemental material required to balance the inflow of precipitation with the outflow of the system. The two key design elements in engineered cover system are the thickness and composition of the material to provide sufficient water storage capacity. Thus, conducting the water balance analysis is the fundamental way to calculate the water storage capacity necessary to avoid leachate generation. The primary elements of a water mass balance include the factors such as precipitation, surface runoff, potential evapotranspiration, infiltration, soil moisture storage, actual evapotranspiration, and potential water flow through the cover system.

It is essential that the leachate generated by the landfill waste does not affect the peripheral ground environment around the waste disposal site. The role of cover system is to effectively prevent the infiltration, and inflow of precipitation and surface water to the waste layer. It is necessary to construct an effective cover system behind the provision of bottom liner system that intercepts water and thus reduces the generation of leachate. Figure 1 shows the details of landfill cover components including the water interception barrier layer system.

The important function of landfill cover system (daily or final) is to minimize the quantity of leakage, which passes through the cover system, and thus reduce the infiltrate in the waste layer. The amount of water that infiltrates into the waste layer depends on the hydrological conditions of the waste disposal region, cross sectional composition of the cover system, top slope of the disposal site, existence of the vegetation etc. The prediction of rainfall and snowfall water infiltration, which generally pass through the cover system, can be simulated using hydrological models. Even though few models are commercially available, HELP (Hydrologic evaluation of landfill performance) model has been widely used in USA to evaluate the rainfall interception effect of landfill cover system.

The analytical solutions may be used for verifying hydrologic model analysis results or detailed design using conservative designs. Infiltration through the cover system can be analytically calculated using two processes such as, i) estimate or calculate the average head of water in the drainage layer above the barrier layer, and ii) calculate percolation through the barrier layer under the average head. The head of liquid in a drainage layer as a function of distance along the layer can be calculated using the differential equation developed by Giroud et al. (1992), whereas the steady state percolation of rain water through a soil barrier can be calculated using Darcy's equation. In the present study, both the surface layer and underlying compacted barrier layers were considered as vertical percolation layers. The presence of plant roots in the cap system removes water by transpiration, and this aspect should be considered in the vertical percolation layer calculations (Benson et al. 1993). Based on the compaction condition, a need to evaluate the hydrology of cover system since the measured hydraulic conductivity can significantly affect the percolation

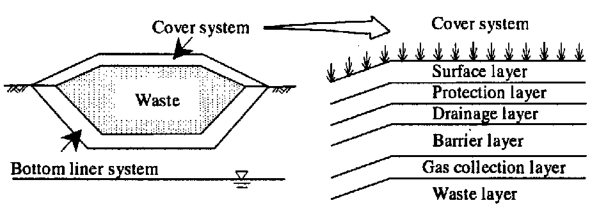


Fig. 1 Landfill water interception system and composition layers of cover system.

prediction. The percolation through the final cover measured at the Live Oak landfill in Atlanta with predicted percolation based on the unsaturated model was reported by Khire et al. (1995).

In this paper, an analytical method of HELP model proposed by Thornthwaite et al. (Koerner et al. 1997) has been used due to its comparatively easiness in evaluating the rainfall water interception effect of the whole cover system. In the present study, the above method was used to apply sludge as barrier layer of landfill final cover system.

## 2. Cover system

### 2. 1 Functions and classification of the cover system

In European and American countries, it has been already recognized that the cover and bottom liner systems of landfill are effective water interception elements for preventing the leachate migration. The construction criteria and evaluation techniques have been already established by many investigators (Daniel 1992; Daniel et al. 1995).

Due to the high-humidity climatical condition of Japan, the cover system that has the function of isolating waste layer and air environment is regarded as an effective leachate administrative structure that suppresses the rainfall infiltration into the waste layer. However, there is no established regulation in the existing disposal sites except the provision of laying earthen cover on the waste layer. Further, there is no properly designed cover system as a water interception structure that can sufficiently suppress the infiltration of rainfalls (Kamon 1999).

Under the classification category of cover system, it has been established that final cover system can permanently prevents the infiltration of precipitation into the disposal site, and daily cover system that suppresses the water which infiltrates into the waste layer during the reclamation stage. Though there are some differences in each structural type, it is similar in the view of preventing the water infiltration into the waste layer.

### 2. 2 Construction criterion of the cover system in USA

In U.S.A., the environmental protection agency (EPA) set the minimum regulation criteria for the construction of waste disposal final cover system based on Subtitle D of Resource Conservation Method for Recovery (RCRA) in 1992. In addition, the regulation in which the state is detailed by location of the disposal site and quality of a waste has been established. As per the recommended construction criteria of EPA, the components layer thickness of the final cover system and hydraulic conductivity standard of the barrier layer are considered as shown in Figure 2. The regulation concept is to prevent the bathtub effect in which the water accumulates in waste layer. Daniel (1995) reported that the hydraulic conductivity of the barrier layer of final cover system has been made equivalent to the bottom liner or ground beneath the landfill (i.e. k is less than or equal to $1 \times 10^{-5}$ cm/s in the case of municipal waste disposal site, and $1 \times 10^{-7}$ cm/s in hazardous waste disposal site). It means that final cover system is made to be a structural type equal to the bottom liner system.

## 3. Application of sludge materials to the barrier layer

In Europe and America, clay material has been generally used as a barrier material since its performance of water interception effect has been found to be excellent to be used in the cover system. In the present study, the application of sludge materials has been examined from the viewpoint of effective reuse of waste materials. Hence, the applicability of paper mill sludge, construction sludge and bentonite mixed construction sludge materials as a barrier layer in the cover system was examined.

It is important to evaluate the hydraulic conductivity aspect of above mentioned sludge materials to use them as barrier layer of cover system. Therefore, hydraulic conductivity tests were carried out using the flexible wall permeameters, and sludge materials at different water contents were tested. Samples of 10 cm diameter and 3 cm height were used, and the density of samples used was according to the standard compaction curve of each material.

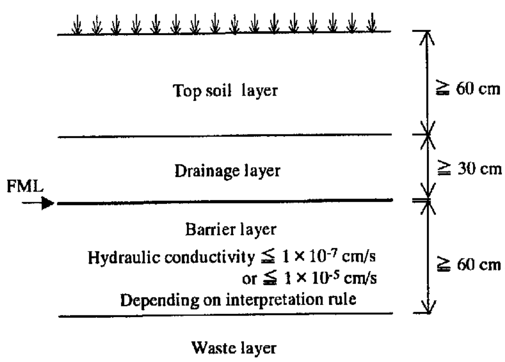


Fig. 2 Recommended construction criterion of the cover system in U.S.A.

Figure 3 shows the hydraulic conductivity test results of paper mill sludge, whereas Figure 4 indicates the hydraulic conductivity details of construction sludge and bentonite mixed construction sludge. In case of PMS, the water content that showed low hydraulic conductivity corresponds to 60% higher than the optimum water content at the wet side. However, there is no remarkable difference in the hydraulic conductivity for the wide water content region of 50 - 150% that showed hydraulic conductivity range of $4 \times 10^{-7}$ cm/s - $9 \times 10^{-7}$ cm/s. Whereas CS showed hydraulic conductivity of $1 \times 10^{-8}$ cm/s - $7 \times 10^{-8}$ cm/s, and CSB indicated lowest hydraulic conductivity of $5 \times 10^{-9}$ cm/s - $7 \times 10^{-9}$ cm/s when compared with PMS. The hydraulic conductivity of CSB is low, and this is an advantage in the construction management since the low hydraulic conductivity can be maintained over an extensive water content region. In U.S.A., the hydraulic conductivity of the MSW landfill barrier layer in the cover system has been determined as less than or equal to $1 \times 10^{-5}$ cm/s; in addition to that, if the hydraulic conductivity is less than $1 \times 10^{-7}$ cm/s, the function of the barrier layer can be demonstrated well in all types of disposal sites. Based on

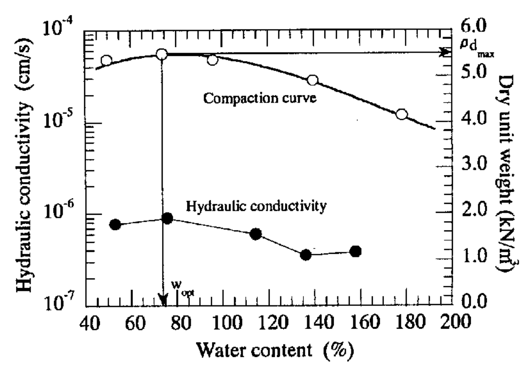


Fig. 3 Hydraulic conductivity of paper mill sludge

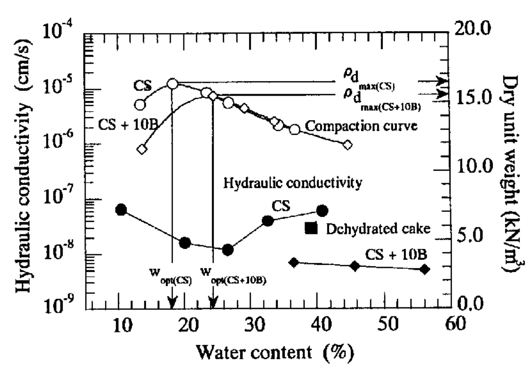


Fig. 4 Hydraulic conductivity of construction sludge and bentonite mixed construction sludge

the above aspect, both CS and CSB materials satisfied the standards set by U.S.A. In the meantime, to apply PMS as the barrier layer, the performance evaluation in the field should be evaluated.

## 4. Effect of the final cover system on rainfall water interception

### 4.1 Calculation method

Figure 5 shows conceptually the migration pathway of water, when the rainfall passes through the waste disposal site of final cover system (Khire et al. 1997).

The precipitation in the disposal site can be minimized by following the below mentioned functions of each layer in the final cover system.

1) evapotranspiration effect in surface layer
2) water retention effect in surface layer
3) surface runoff effect of the precipitation by the surface inclination.
4) the drainage effect by drainage layer.
5) low permeability effect of the barrier layer.

The fundamental aspect in evaluating water transport is mass conservation law. When the precipitation passes through earthen cover surface layer to drainage layer, the above law can be followed, and the water balance can be calculated as follows (Khire et al. 1997).

$$I = P - R - S - Et \qquad (1)$$

where, I is the infiltrated water quantity of the drainage layer, P is the precipitation in the disposal site, R is the surface runoff of the disposal site, S is the quantity of water that is retained in the surface layer, Et is the amount of water loss due to evapotranspiration.

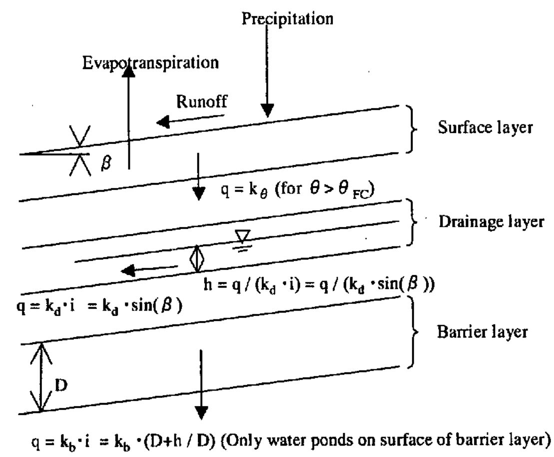


Fig. 5 Water transport conceptual scheme in the final cover system

Using the above equation, quantity of water that infiltrates to the drainage layer can be obtained. In the drainage layer, some amount of water can be drained in the inclination direction as per the Darcy's rule as showed in Equation (2) (Othman et al. 1995).

$$h = \frac{q}{k_d \cdot i \cdot 1} = \frac{q}{k_d \cdot \sin(\beta) \cdot 1} \qquad (2)$$

where, h is the water level in the drainage layer, q is the infiltration flow quantity of the drainage layer, $k_d$ is the hydraulic conductivity of drainage layer, and $\beta$ is the angle of drainage layer.

According to the Darcy's law, the quantity of water, which leaks out from the barrier in the same as that of whole final cover system, which can be obtained using the following equation.

$$q = k_b i A = k_b \frac{h + D}{D} \cdot 1 \qquad (3)$$

where, q is the quantity of water that percolates from the barrier layer, $k_b$ is the hydraulic conductivity of the barrier layer, and D is the thickness of barrier layer.

To examine the water interception effect of final cover system in the landfill, the case study of waste disposal site in each site condition should be investigated. The necessary parameters that concretely set in each characteristic value of final cover system of constitution layer in shown in Equation (1). Next the water leakage quantity from the final cover system is obtained by calculating the water balance using Equations (1) to (3). The factors that has to be evaluated in the above scenario are, 1) evaluation and comparison of water interception effect for the weather conditions of the landfill sites, and 2) the evaluation of water interception effect as hydraulic conductivity and layer thickness changes in the barrier layer that applies to the usage of sludge.

### 4.2 Geographical effect

Japan has the average annual precipitation of 1760 $mm/m^2/y$, and the humid meteorological weather condition phenomenon in comparison with Europe and America. The Japanese land is long in north and south, and the temperature and climatical environment of the precipitation vary largely by region and season based on the mountain range. However, there is no evaluation for water interception effect of the final cover system constructed in the waste disposal site of Japan. An evaluation was carried out by considering the weather conditions of each landfill site with respect to the rainfall water interception effect of final cover system to apply the sludge materials as barrier layer system. In the above calculations, monthly average precipitation and monthly mean temperature were used as input data for each month and place for the past 30 years. The setting characteristic values of structural profile and each layer of the final cover system are shown in Figure 6. The hydraulic conductivity of the barrier layer using sludge with achievable hydraulic conductivity of $1 \times 10^{-7}$ cm/s has been considered in this study. The earlier hydraulic conductivity laboratory works carried out on sludge samples (using flexible wall permeameters for both PMS and CS) showed low hydraulic conductivity of less than or equal to $1 \times 10^{-7}$ cm/s (Kamon et al. 1999; Kamon et al. 2000). In addition to that, the above referred value is a reference value of U.S.A. landfill covers hydraulic conductivity.

Table 1 and Figure 7 summarize the annual cumulating flux values of the water balance in final cover system as the rainfall fell in waste disposal site at each tested location. The flux is amount of water corresponds to unit time per unit area. In the present state of waste disposal site in Japan, construction of only surface layer earthen cover is in practice as shown in Figure 2. If it is such structural type, water interception rate is defined as the ratio of infiltrating water or percolation water for the precipitation in the form of equation (4), which is about 28% - 72% of each location. The water interception effect by surface layer of earthen cover is directly dependent on the weather conditions of the disposal site, and water interception rate in a region of low precipitation.

$$W.I.E. = \left(1 - \frac{Percolation}{Precipitation}\right) \times 100 \qquad (4)$$

Where, W.I.E. is water interception effect (%)

It is established that the drainage and barrier layers have been set below the surface layer of earthen cover to make them impervious. In the final cover system of proposed study, it has been observed that the rainfall water interception rate by the final cover system is high ( 97% - 99%), which shows almost complete sealing of the whole quantity of percolated water. Water interception rate of the final cover system tends to increase in the region of high precipitation. It has been observed that the highest water interception effect in the Owase of Mie Prefecture indicated more precipitation. The amount of water leaked through the barrier layer is almost fixed, without relating to the regional difference of precipitation. This tendency is clear even in Figure 7 and, therefore, the water interception effect of final

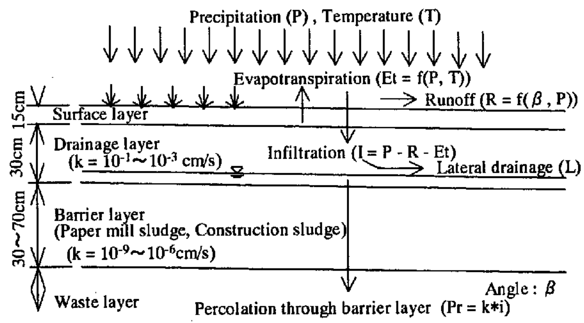


Fig. 6 Schematic view of water balance model in the final cover system

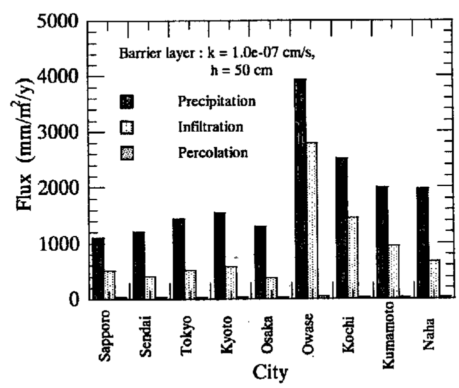


Fig. 7 Water balance in the final cover system of selected sites

Table 1 Rainfall water interception effect of final cover system installed in each place

| | Latitude (A) | Temperature (B) (℃) | Precipitation (C) (mm/m²/y) | Runoff (D) (mm/m²/y) | Evapotaranspiration (E) (mm/m²/y) | Infiltration (F) (mm/m²/y) | Percolation (G) (mm/m²/y) | Water interception effect of surface layer (H) (%) | Water interception effect of cover system (I) (%) |
|---|---|---|---|---|---|---|---|---|---|
| Sapporo | 43°03′ | 8.43 | 1106.30 | 88.50 | 506.84 | 510.95 | 33.15 | 53.81 | 97.00 |
| Sendai | 38°16′ | 12.03 | 1205.10 | 96.41 | 700.71 | 407.98 | 32.74 | 66.15 | 97.28 |
| Tokyo | 35°41′ | 15.78 | 1439.60 | 115.17 | 815.90 | 508.53 | 33.14 | 64.68 | 97.70 |
| Kyoto | 35°01′ | 15.48 | 1544.70 | 123.58 | 841.02 | 580.10 | 33.43 | 62.45 | 97.84 |
| Osaka | 34°41′ | 16.37 | 1296.00 | 103.68 | 824.05 | 368.27 | 32.58 | 71.58 | 97.49 |
| Owase | 34°04′ | 15.69 | 3929.60 | 314.37 | 821.58 | 2793.65 | 42.28 | 28.91 | 98.92 |
| Kochi | 33°33′ | 16.45 | 2515.80 | 201.26 | 872.60 | 1441.93 | 36.87 | 42.69 | 98.53 |
| Kumamoto | 32°49′ | 16.30 | 1990.10 | 159.21 | 877.80 | 953.09 | 34.92 | 52.11 | 98.25 |
| Naha | 26°12′ | 22.57 | 1973.00 | 157.84 | 1148.94 | 666.70 | 33.77 | 66.21 | 98.29 |

H = ( 1 - F/C )×100 , I = ( 1 - G/C )×10(

Barrier layer in cover system : k = 1.0e-07 cm/s, h = 50 cn cover system is increased in the region of high precipitation. Figure 8 shows the monthly variation of hydraulic gradient, which affected the barrier layer for each site. From Figure 8, it can be seen that there is not much effect of the hydraulic gradient that affected the performance of barrier layer (50cm thickness); even if the infiltrated water that passes through the surface layer of earthen cover changes, which depends on the precipitation. The effect of hydraulic conductivity on the barrier layer seems to be excellent from percolation point of view to be used in the final cover system.

### 4. 3 Interception of the rainfall water

The effect of final cover system on the rainfall water interception effect was evaluated for the change in hydraulic conductivity and layer thickness of the barrier layer. Figures 9 and 10 shows the change of water balance in the final cover system which set the barrier layer hydraulic conductivity of 1 × 10-7 cm/s and thickness of 50 cm at Owase and Kyoto. From these Figures, the precipitation of Kyoto in August is more abundant than the precipitation in winter. Even though the surface layer of earthen cover allows the water to pass through, the infiltrating quantity of water to drainage layer is dependent on the precipitation. Further the infiltration is reduced by the increase in evapotranspiration for the period corresponds to high temperature. However, regardless of the variation of hydraulic gradient (i = 1.1 - 1.8) in Owase, the quantity of water percolation from the barrier layer is almost fixed (3.52 $mm/m^2$/month) throughout the annual that is equivalent even in Kyoto. This has been explained by the Darcy's rule since percolation quantity of water from the barrier layer is determined by hydraulic conductivity and hydraulic gradient. The change of the hydraulic gradient at low hydraulic conductivity, $1 \times 10^{-7}$ cm/s hardly affects the percolation quantity. Figure 11 shows that the yearly average hydraulic gradient for the layer thickness of barrier layer usually considers 50 - 90 cm while construction. The variation of hydraulic gradient at Kyoto and Owase are 1.04 - 1.07 and 1.20 - 1.35 respectively. There is not much variation of hydraulic gradient in constructing the barrier layer thickness. Figure 12 shows the rainfall water interception rate of yearly average for hydraulic conductivity of the barrier layer in Owase. If the barrier layer that ensures under $1 \times 10^{-7}$ cm/s of hydraulic conductivity for a thickness is 30 cm - 70 cm, rainfall water interception rate at 100% in the each area can be achieved. In Figure 13, the relationship between the barrier layer thickness and

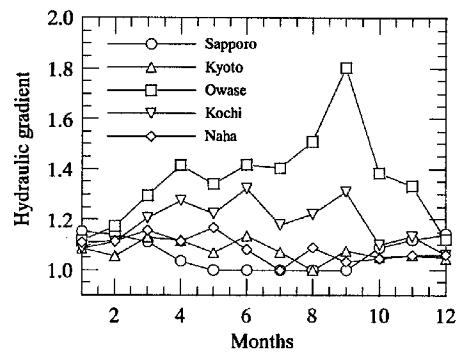

Fig. 8 Monthly variation of hydraulic gradient in the barrier layer of selected sites

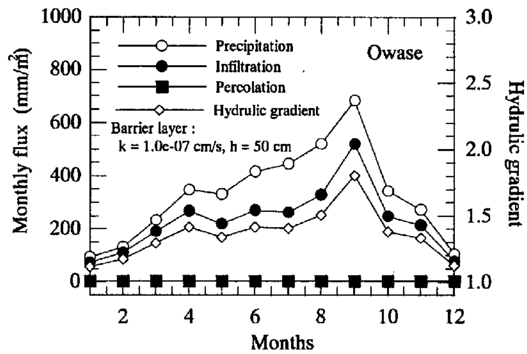

Fig. 9 Change of the water balance in the final cover system (Owase)

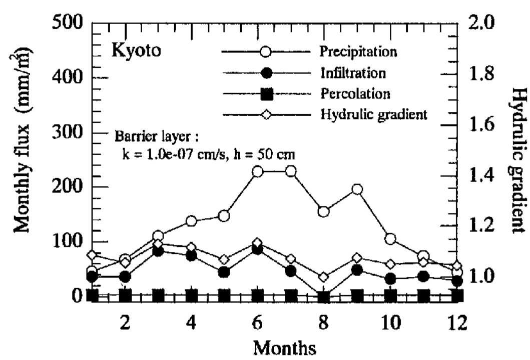

Fig. 10 Change of the water balance in the final cover system (Kyoto)

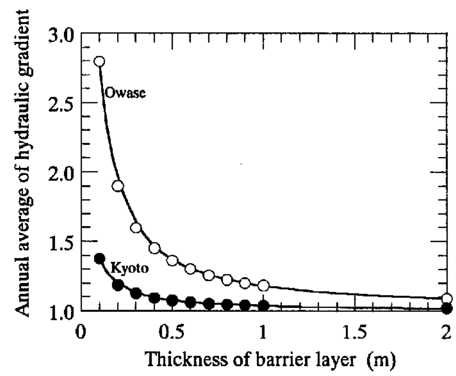

Fig. 11 Relationship between the barrier layer thickness and average hydraulic gradient

rainfall water interception rate in the same district is shown. If the assumed hydraulic conductivity of the barrier layer is $1\times10^{-7}$ cm/s for a layer thickness over 10 cm, there is no effect of the hydraulic gradient that affects barrier layer on the percolation quantity of water, and the water interception rate over 95% could be possible.

# 5. Effect of the daily cover system rainfall water interception

## 5. 1 Calculation method

In evaluating the rainfall water interception effect by daily cover system, the validation of weather condition of the day unit has to be considered. The water balance calculation fundamentally is the same as mentioned in Chapter 3. The input data of weather condition estimation in disposal site used was day unit precipitation and day unit mean temperature of fiscal 1998. The calculation period considered is 1 month for the exposure period of the daily cover system. The assumed layer structure of the daily cover system is shown in Figure 14, and the water interception effect is evaluated by two-layer structure type which laid surface layer earthen cover of the sludge barrier system.

## 5. 2 Water interception

Figures 15 and 16 shows the validation of 1 month precipitation in Owase and Kyoto. In addition to that the percolation flux of the daily cover system with hydraulic conductivity of $1\times10^{-6}$ cm/s and $1\times10^{-7}$ cm/s for a thickness of 60 cm in barrier layer is shown. Though the daily variation of precipitation flux and infiltration flux from the surface layer earthen cover is maximum, the quantity of percolation water from the cover system is small if the barrier layer hydraulic conductivity is $1\times10^{-6}$ cm/s which is almost zero when the hydraulic

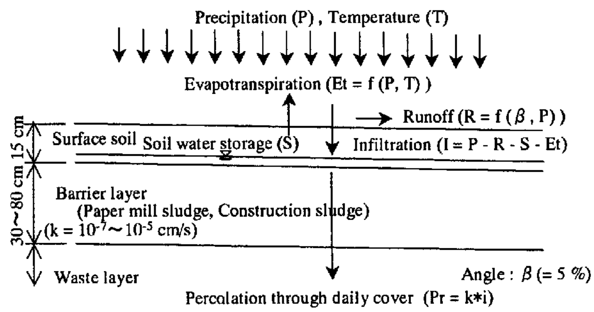


Fig. 14 Water balance model in the daily cover system

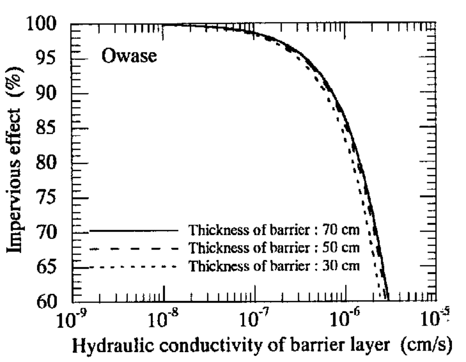


Fig. 12 Hydraulic conductivity and rainfall water interception rate of the barrier layer

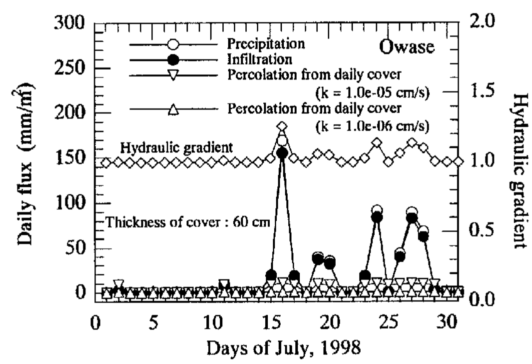


Fig. 15 Daily change of water balance in daily cover system (Owase)

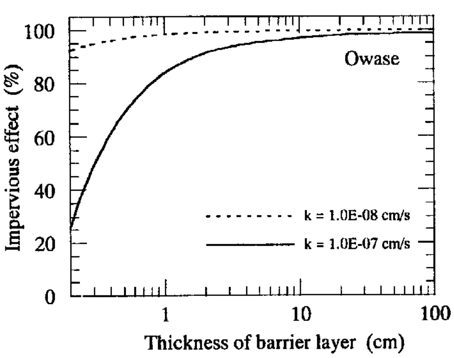


Fig. 13 Barrier layer thickness vs. rainfall water interception rate

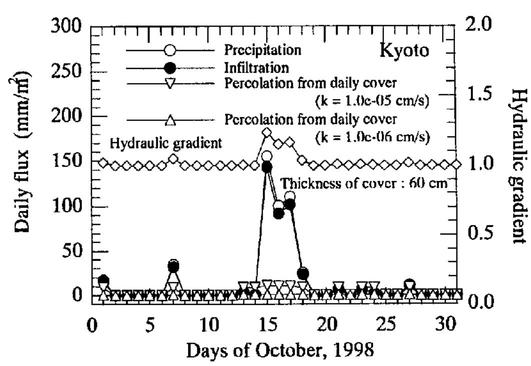


Fig. 16 Daily change of water balance in daily cover system (Kyoto)

Table 2 Conditions of the disposal site set by case study

| | Waste | Barrier layer in daily cover system | Barrier layer in final cover system | Surface layer |
|---|---|---|---|---|
| Unit weight (Wet) ($gf/cm^3$) | 0.6 | 1.17 | 1.17 | |
| Height (cm) | 300 *1 | 60 *1 | 95 | 15 |
| Water content *2 (%) | 20 | - | - | - |
| Hydraulic conductivity (cm/s) | - | $1\times10^{-6}$ | $1\times10^{-7}$ | - |
| Selected region | Owase | | | |
| Total number of lifts | 5 (with an increment of one layer / year) | | | |
| Duration of waste filling | 5 years | | | |

*1 Height of one lift
*2 Water content = (Liquid mass / Total mass) x 100

conductivity of the barrier layer is $1\times10^{-7}$ cm/s. It can be concluded that the water interception effect in the barrier layer for the rainfall is high, as the utility in the short period such the daily cover system is required.

## 6. Effect of cover system on leachate reduction

In this chapter, leachate depression effect by cover system installation was examined by quantifying the leachate quantity that generates from waste layer from the beginning of waste filling to post closure period of land fill.

### 6.1 Method

During ,the initial and final stages waste filling, application of both daily cover and final cover systems was assumed. From the starting day to the final state of waste materials filling, the operation of disposal site is in a balanced state and the leachate quantity from the waste layer was calculated on the basis of water balance aspect (Tchobanoglous et al. 1998). The balanced state means the period until the quantity of water, which infiltrates to the waste layer and leaching quantity of water becomes equal. All conditions of the disposal site used by case study are shown in Table 2. The annual waste materials landfill height is 300 cm, and the daily cover system of the height which corresponds to 20% of the waste layer thickness at the end point of construction time. In the meantime, the reclamation of waste ends by 5 years, and the operation of disposal site completes by the installation of the final cover system for a layer thickness of 95 cm. Figure 17 shows the definition of disposal site model and water balance model used for the case study. The quantity of water that infiltrate into the waste layer should use annual cumulative value of the percolation quantity from the each cover system in order to consider the water interception effect by daily cover and final cover systems.

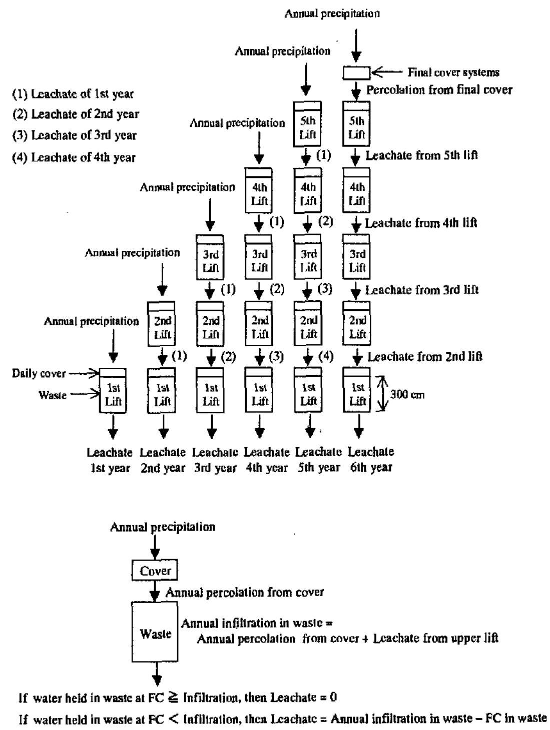


Fig. 17 Schematic diagram of waste landfill model

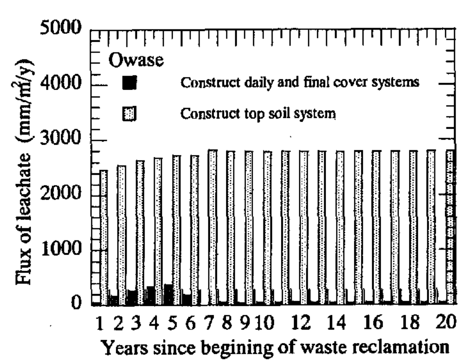


Fig. 18 Construction effect of the cover system vs. flux of leachate

### 6.2 Leachate reduction

The calculation results shown for passed years from the landfill to the start of waste filling is shown in Figure 18. For the present state of disposal site in Japan, the installation of only surface earthen cover after the land fill completion is in practice by using the daily cover system and the leachate quantity generated during the land fill period is about 1/10. By installing the final cover system, the leachate is reduced after the landfill completion is about 1/60. It can be said that the installation effect of cover system is great for the reduction in leachate quantity of disposal site.

## 7. Conclusions

From the above study, the following conclusions can be drawn.

1) The tested sludge materials met the regulatory criteria of HC that showed promising results as an alternative for landfill cover materials, and they can be used as an efficient barrier system since the percolation through barrier layer is low (2.6 to 5.7%).
2) The results of the hydraulic conductivity tests revealed that low hydraulic conductivity (atleast $1 \times 10^{-7}$ cm/s) of sludge materials such as PMS, CS, and CSB is necessary to apply as barrier layer of the cover system.
3) The rainfall water interception effect of final cover system using sludges in the waste disposal site showed approximately 100% impervious in all selected sites of Japan.
4) If the drainage and barrier layers are installed below the surface layer of final cover system, there is no effect of the hydraulic gradient, and its effect of the barrier layer on percolation quantity of water can be ensured. (if the hydraulic conductivity of the barrier layer was assumed to be $1 \times 10^{-7}$ cm/s, and thickness over 10 cm).
5) The quantity of percolation water from the daily cover system is small in the case of hydraulic conductivity of the barrier layer is $1 \times 10^{-6}$ cm/s. In addition to that, the water interception effect of daily cover system is high, as the utility in the short period is required.
6) The construction of the cover system effect is significant for the reduction in leachate quantity of the disposal site.

## Acknowledgement

The support provided by Japan Society for the Promotion of Science (JSPS) for Dr.G.Rajasekaran's research work at Kyoto University is greatly acknowledged. Also, the authors wish to express their appreciation to Fuji Industrial Research Institute of Shizuoka Prefecture and Idehiko Paper Manufacturing Co. Ltd, and Kumagai Gumi Co. Ltd for providing the PMS and CS samples respectively.

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## 要　旨

廃棄物処分場に設けられるカバーシステムの主要な目的は，降雨の廃棄物層への浸透を最小化することであり，カバーシステム内バリア層の低透水性の確保が重要因子となる。これまで著者らは，バリア層への汚泥の適用性を室内試験より明らかにしている。本研究では，バリア層へ汚泥を適用したカバーシステムにおける降雨遮水効果を水分収支モデルによって明らかにするものである。その結果，透水係数 $1\times10^{-7}$ cm/s，層厚 10 cm 以上を確保できるバリア層を有するカバーシステムであれば，日本各地の気象環境下で，ほぼ全量の降雨が遮水可能な結果が得られた。

**キーワード**：廃棄物処分場，カバーシステム，降雨遮水効果，透水係数，汚泥