JICA Training Text

Caution for Application of “Fukuoka Method”

(Semi-Aerobic Landfill Technology)

2007

Prepared by Japanese International Cooperation Agency –

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Basic Standpoint in Writing

1. What is the "Fukuoka Method"?

The Fukuoka method is a type of sanitary landfill based on a semi-aerobic landfill structure.

It is called the Fukuoka method because it was jointly developed by Fukuoka University and Fukuoka City.

The Fukuoka method is a technology offering improved landfill sites simply and at low cost utilizing materials and methods readily available in developing countries to install leachate drainage pipes and gas vents, thereby enlarging the aerobic region in the landfill waste layers. The Fukuoka Method also minimizes impact on the environment surrounding the site because it promotes the degradation of landfilled waste, rapid landfill stabilization and leachate is drained promptly from the landfill. In addition the volume of methane gas emitted by the landfill is reduced, contributing to efforts to prevent global warming.

2. Relationship between the "Fukuoka Method" and the anaerobic landfill technology

The Fukuoka method is one waste disposal technology that can be utilized in many locations around the world, but unlike anaerobic landfills collecting biogas, the interior of the landfill is maintained in an aerobic state as much as possible, specifically to promote rapid stabilization and environmental preservation.

It is impossible for aerobic and anaerobic environments to coexist, so this text is designed for implementation in sites where biogas is not collected.

The text describes the Fukuoka Method, but the authors do not in any way suggest that it should be used to replace anaerobic landfills with biogas collection.

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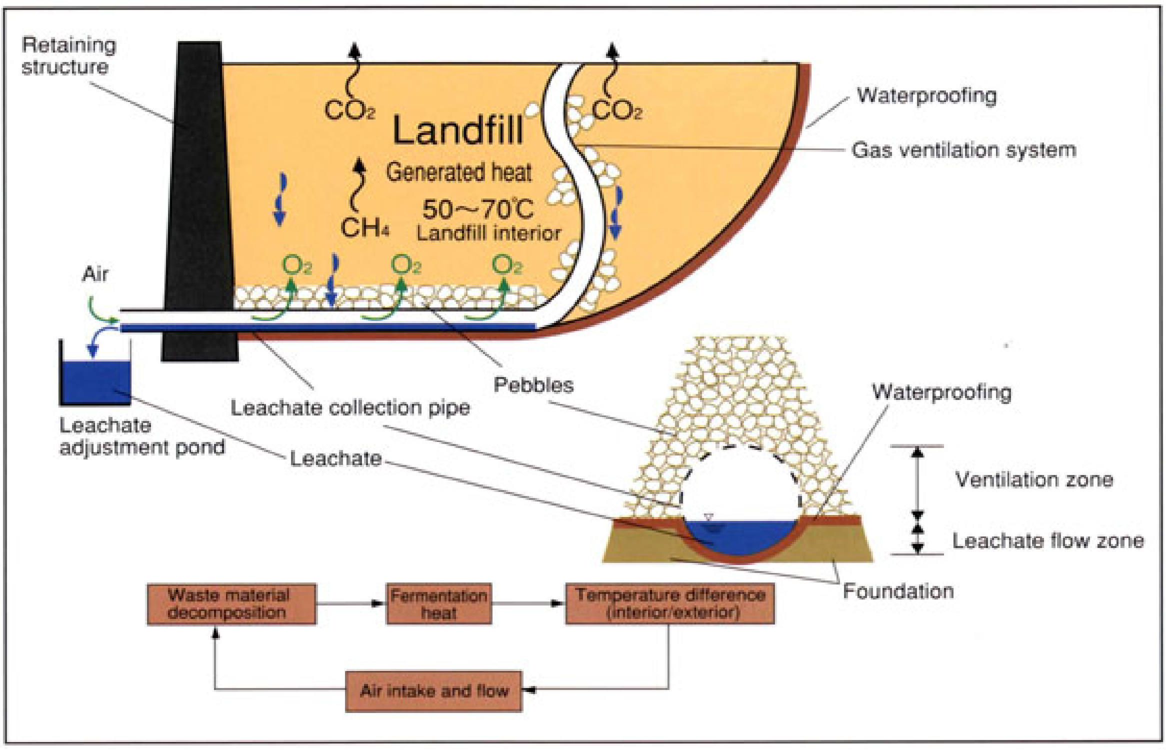
Introduction

As urbanization progresses, particularly in various countries in Asia, waste management issues are becoming exposed and they are becoming more urgent day by day. Cleaning operation is in general made up of 4 processes: collection, transportation, treatment, and disposal. While a certain amount of improvement has been seen in the waste collection in developing countries in the last ten years, most waste disposal sites are still using open dumping and open burning and this is connected to several types of environmental pollution.

Photo: Current situation of slum   Source: UN-HABITAT

However, in developing countries, there are a lot of economical and technical problems with high level landfill technologies of first world countries making implementation of improvement not feasible. Therefore, there is significant need for transfer of landfill technology that is simpler, low cost, and that can be maintained locally. A method that provides this that has recently gathered attention is the Fukuoka Method (semi-aerobic landfill).

The “Fukuoka Method” (semi-aerobic landfill) is a landfill construction method for landfill disposal sites developed jointly by Fukuoka University and Fukuoka City starting in 1965. A semi-aerobic landfill structure is preparing a collection and discharge pipe with a large cross section in the bottom of the landfill that rapidly collects and discharges leachate away from the landfill site and in addition enables natural inflow of atmospheric air into the landfill via the collection and discharge pipe in the bottom driven by convection generated by fermentation heat of waste material. In addition, gas venting facilities are also constructed at appropriate intervals to increase the aerobic environment in the landfill. This enables the landfill to naturally become aerobic which in turn enables fervent activity of aerobic microorganisms in the waste material promoting decomposition of landfilled waste, reducing BOD in the leachate, and suppressing generation of methane gas.



Compared to anaerobic landfills where there is little air in the landfill, when converting a landfill to semi-aerobic, the gas that is primarily generated becomes carbon dioxide and therefore contribution to global warming is estimated to be reduced to approximately 1/2 (the heat absorption value that is the global warming potential of methane is 21 times that for carbon dioxide). Furthermore, this structure rapidly removes leachate, suppressing permeation of leachate underground and therefore also has the effect of reducing effect on groundwater.

The “Fukuoka Method” has characteristics of being a simple structure and having low cost and therefore is a technology that can be applied with materials that can be obtained locally in developing countries and therefore has already been implemented in several developing countries. Especially technical cooperation operation of improving a landfill disposal site in Malaysia by JICA integrated this method which has brought significant success. In addition, there have been reports of technology transfer to Iran, China, Mexico and Oceana etc. and it is gathering a lot of international attention. It is evaluated highly as an appropriate technology for waste disposal and JICA targets proactive utilization of this technology and they have prepared JICA-NET teaching materials and are strengthening technology transfer and technology leadership. At this developing countries have recently gained interest in a lot of method received by trainees of training in particular by Japan.

Photo: Example of technical transfer
(Left) China: UN-HABITAT, (Right) Malaysia: JICA

Based on the opportunity of the example of success of the transfer of technology to Malaysia of this Fukuoka Method, there have been requests for cooperation from a lot of countries. The number of trainees in the waste management field that Fukuoka University has received through JICA is about 500 persons from 75 countries over the last 10 years, but it is difficult to say that response has been sufficient for them all. One issue is that the teaching material used for the training, especially the teaching material translated into English, did not sufficiently get across the design.

This project has been implemented as a consigned work from JICA, primarily to develop training material for use in overseas technology transfers, to help ensure the accurate transfer of the basic principles and basic ideas of the Fukuoka Method (semi-aerobic landfill). The Fukuoka Method is attracting increased attention, and this document provides a discussion of points for application of the Method based on the investigation on existing information and material considered necessary for international technology transfer.

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This document is expected to be utilized in future training courses regarding waste management, promoting adequate understanding of the method and its application. It is anticipated that the Fukuoka Method will be more fully utilized in developing countries.

In conclusion, I would like to express my heartfelt gratitude to members of the program supporting committee and the working group for their support and cooperation.

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1. Site Location, Planning Stage

1-1 Considerations for Amount of Precipitation

【Abstract】
The “Fukuoka Method” is a technology for activation of reduction of organic material using aerobic microorganisms through providing an aerobic environment to the extent possible inside landfills to lessen the burden on the environment and promote stabilization. However, unless there is a minimum amount of moisture in the landfill layer, the microorganisms are not active and degradation also does not make progress. Therefore, in regions where precipitation is low, in addition to ensuring a soil covering to the extent possible for preventing the landfill waste material from drying out, storage, and circulation of leachate in the landfill must also be considered to ensure that leachate does not flow out of the landfill and to ensure there is a sufficient amount of water in the landfill.

【Explanation】

(1) Requirements

The weather conditions of developing countries is diverse; as shown in Fig. 1-1, the amount of precipitation is 3,000 mm in some places and in other countries precipitation doesn’t even reach 500 mm. In areas where there is sufficient rainfall, it is not necessary to consider the amount of water in landfill layers. However, in the case of areas with weather conditions with only a small amount of precipitation over a long period of time, the amount of water included in waste brought in, amount of leachate generated through aerobic decomposition, precipitation in the landfill and dirty water in the area surrounding the landfill need to be considered. In addition the selection of location and planning are needed to ensure there is sufficient water in landfill layers.

Incidentally, the environmental conditions required for aerobic microorganism activity is as shown in Table 1-1. Furthermore, the mechanism for the “Fukuoka Method” (Semi-aerobic Landfill Structure) for generating an atmosphere inside landfills that is as aerobic as possible is shown in Fig. 1-2.

Growing conditions of aerobic microorganisms

Item	Limits enabling growth
Oxygen concentration	>1%
Moisture content	20～60％
pH	5 ~ 9％
Temperature	15 ~ 40％

Table 1-1 Environmental conditions of landfill layer for aerobic microorganisms

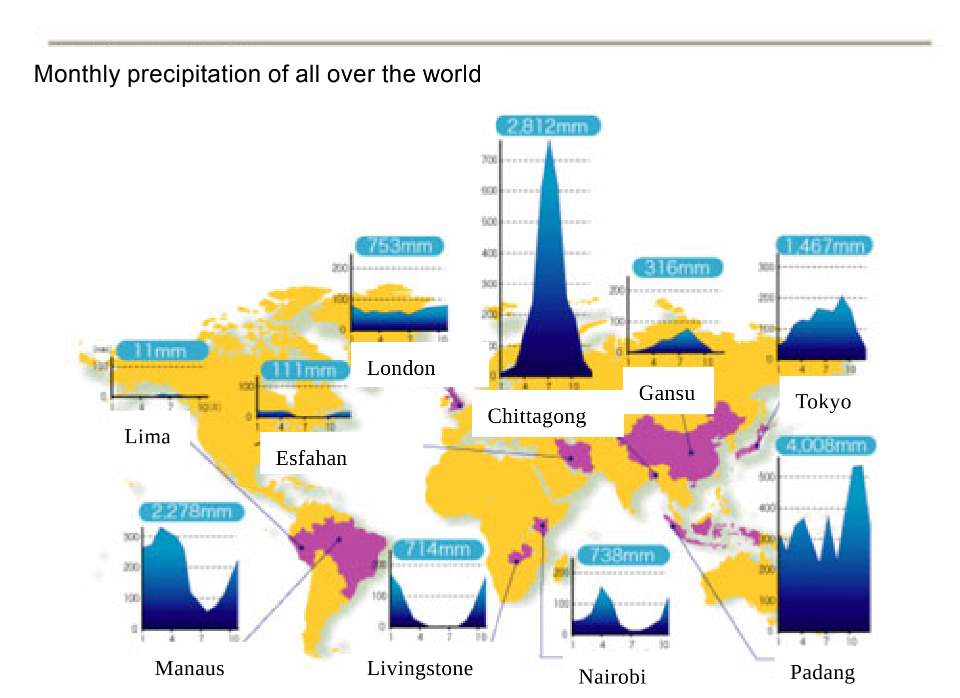


Fig. 1-1 Rainfall in various parts of the world

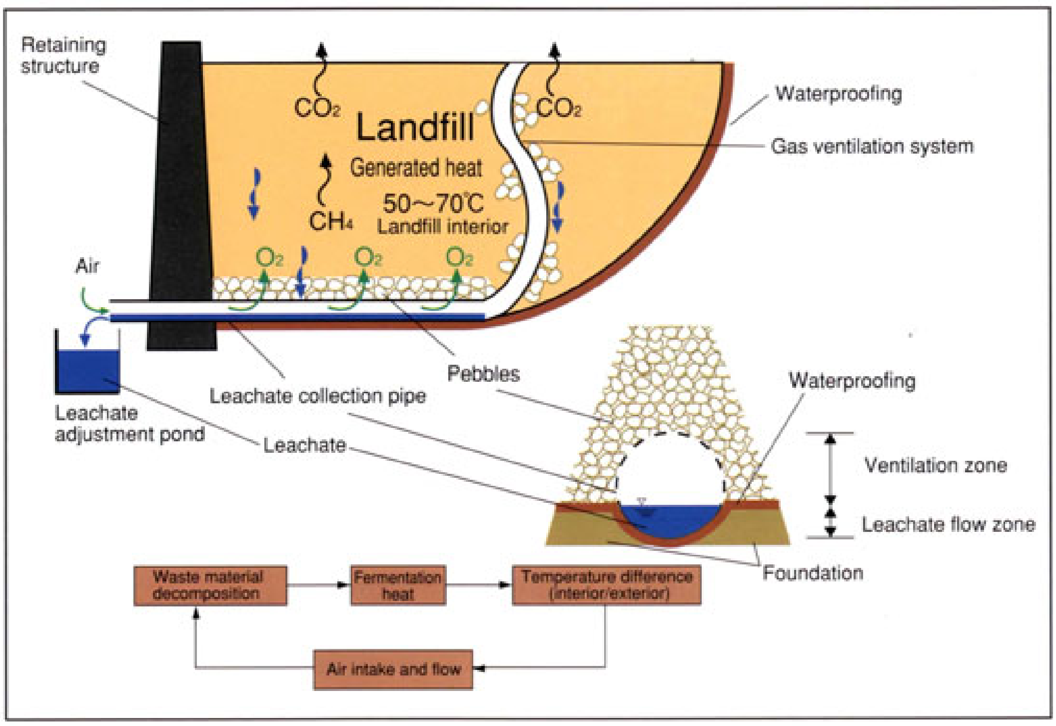


Fig.1-2 Fukuoka Method configuration illustrative diagram

(2)Application Example

In order to maintain water content growth conditions of aerobic microorganisms in a landfill layer in dry regions, daily soil covering and introduction of a leachate circulation system prepared to control sufficient leachate have been thought of.

1-2 Considerations for Temperature

【Abstract】
In order to achieve the characteristics of the "Fukuoka Method" which are stabilization of the landfill layer, quality of leachate, and suitability of the generated gas quality, consideration for activation of the aerobic microorganisms inside the landfill layer is a requirement. From a temperature standpoint, a temperature of 15°C or higher must be maintained inside the landfill layer (temperature inside gas venting pipes). Therefore, especially in cold areas, control is needed to prevent cold air from entering via the leachate discharge pipe opening.

【Explanation】

(1) Requirements

Microorganisms in landfill layers are vigorously active between 15 and 40°C, decompose organic material in the landfill layer and stabilize the landfill layer. It follows that it is necessary to give consideration to the temperature in the landfill layer. In other words, it is necessary to control the landfill area in a manner that the landfill layers maintain a temperature of at least 15 °C. Furthermore, in extremely cold areas, leachate freezes making it so leachate can not be circulated as well as possibly blocking the discharge opening of the leachate discharge pipes. In this case, the leachate discharge pipe openings and pump pits must be constructed in a manner such that they can be kept warm.

Even if the surroundings temperature is high, exceeding the growth conditional temperature for aerobic microorganisms of 40 °C is rare. Therefore, it is thought that this does not need to be considered when considering location and in the planning stage and it is thought that replenishment of water through circulation of leachate etc. has the effect of suppressing heat generated inside the landfill layer.

(2) Application Example

1) The following actions can be considered for cold regions.

(i) If the temperature inside the landfill (temperature inside the pipes for removing gas, is lower than 15 °C, partially block off the discharge opening of the leachate collection discharge pipe to control flowing in of cold air and raise the temperature inside the landfill layer above 15 °C.

(ii) In cases where the temperature of the leachate may get lower than 0 °C, warm the leachate discharge opening to prevent it from dropping below 0 °C due to outdoor air.

(iii) Based on financial conditions, cover the leachate discharge openings with a building or putting the leachate collection pit underground as methods for maintaining warmth.

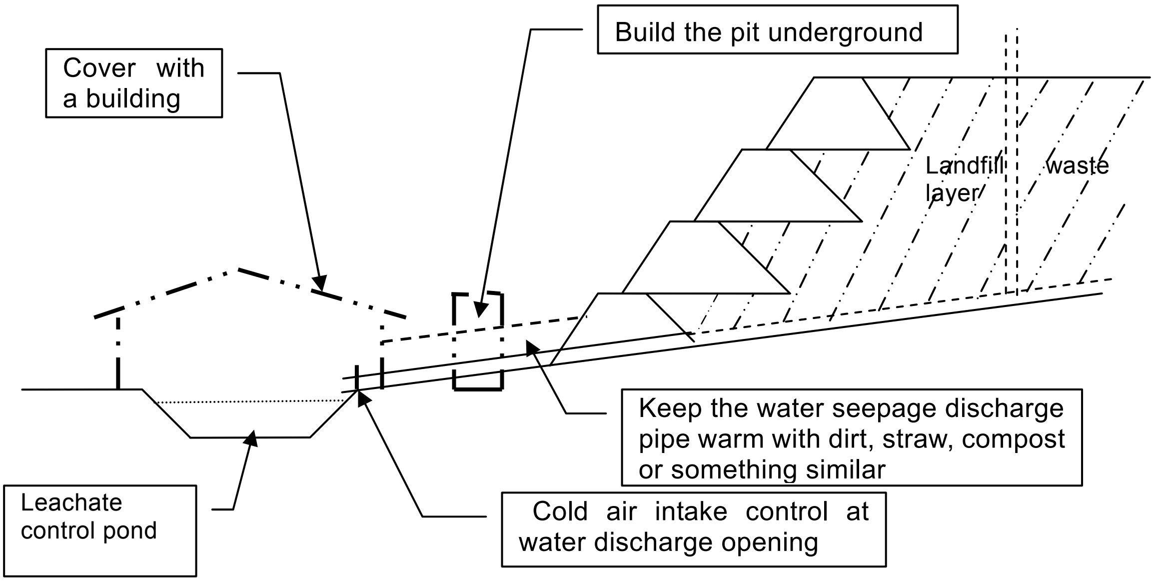


Fig. 1-3 Illustrations for low temperature countermeasures for cold areas

Picture 1-1 Example of covering the leachate treatment facilities with a building (Korea: Pusan)

1-3 Considerations for a Soft Foundation

【Abstract】
In the "Fukuoka Method" enabling natural flow of fresh air into the landfill layer through the leachate collection discharge pipes is essential. However, in conjunction with subsidence of the base of a soft foundation, the leachate collection discharge pipe also sinks making it so the gradient can not be maintained; leachate pools up and prevent influx of air. Furthermore, there are cases where cracks are formed in the bank of the retaining dike made of earth. These phenomena cause a loss of function for landfills of the "Fukuoka Method". Therefore, appropriate steps must be taken at the design stage and the operation and maintenance stage. However, soft foundations are generally impermeably layers making seepage control easy and therefore these areas are not inappropriate areas.

【Explanation】

(1) Requirements

In areas where the landfill is on top of a soft foundation, there are cases where the gradient of the leachate collection discharge pipes placed underground in the landfill layer changes due to differential settlement causing the leachate collection discharge pipe to become submerged and making so it is not possible to ensure surface area for flowing in of air. It follows that in the case of piling up a landfill on an area with a soft foundation, the design must be performed with consideration of settlement of the soft foundation.

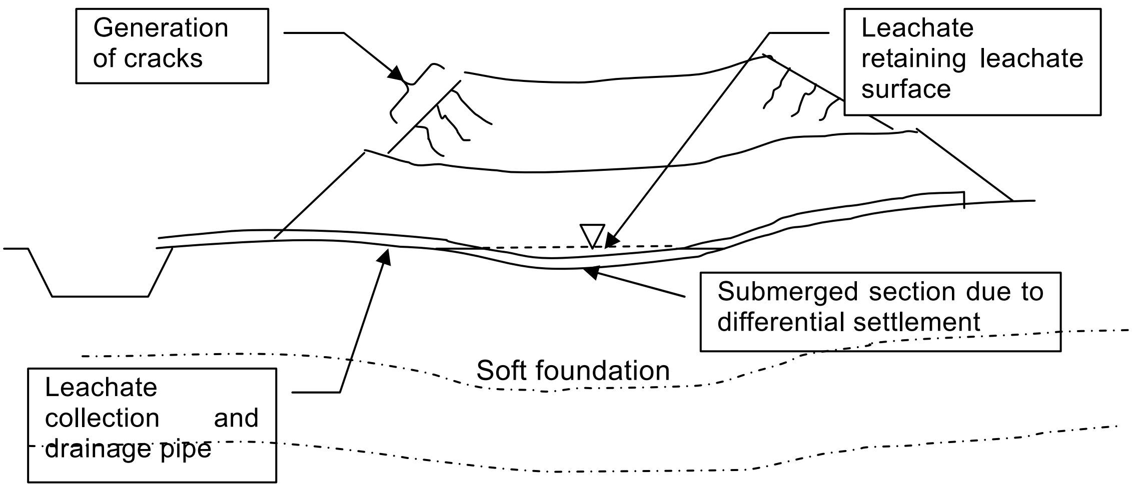


Fig. 1-5 Problems caused by settling

(2)

(2) Application Example

For handling of leachate collection discharge pipes include a method of providing of a significant gradient of the foundation of the landfill and a method for considering settlement when setting the gradient of the leachate collection discharge pipe.

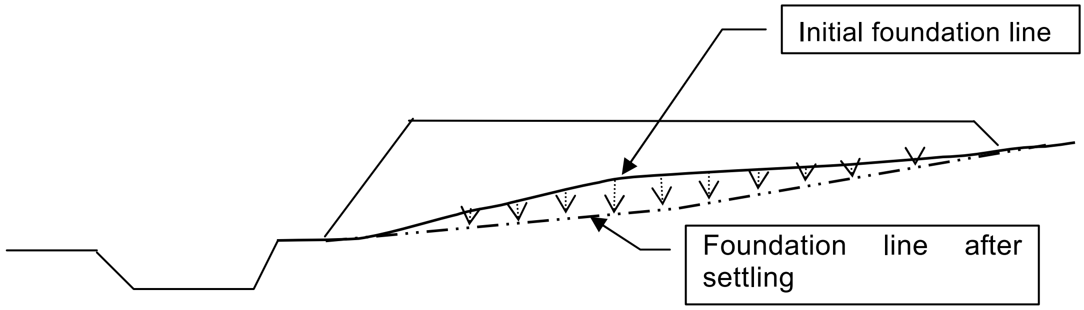


Fig. 1-6. Countermeasure using foundation construction shape

In areas that have localized soft foundation, generally substitution (method of removing soft foundation area and replacing with material of good quality) is used, but there are also methods of increasing the support of the foundation such as driving in pine sticks or blading timber footings or rough material.

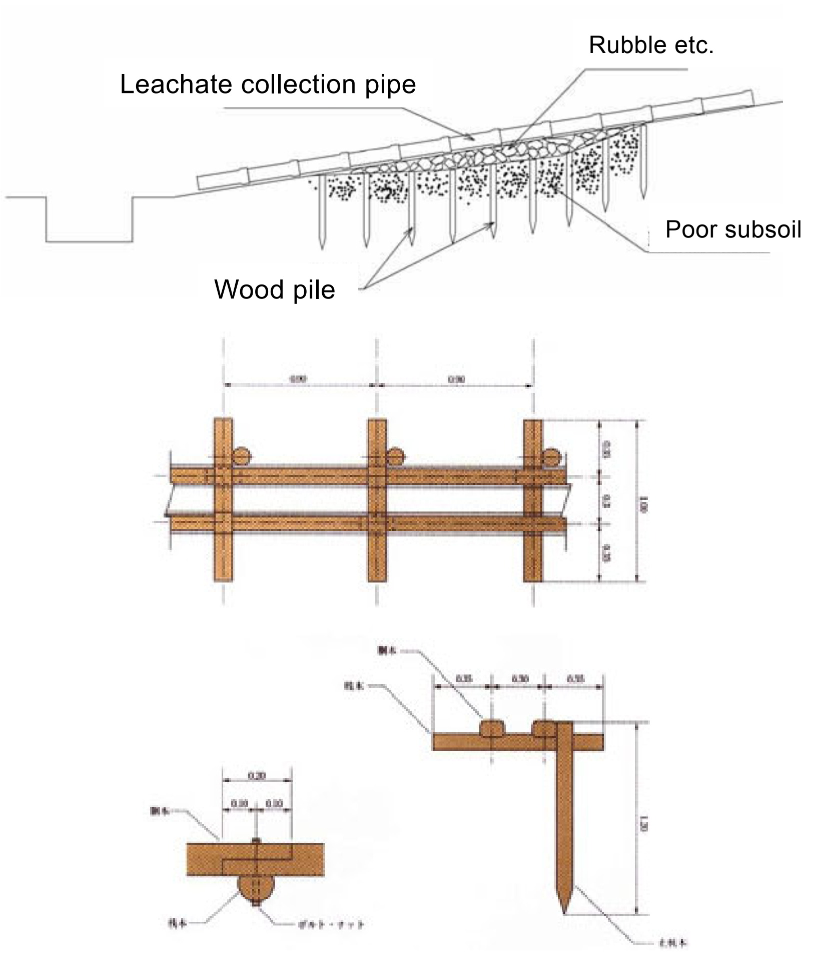


Fig. 1-7 Example of improving soft foundations using stakes

Driving a dense amount of wood stakes using a backhoe etc.

Spread rough material etc. between the wood stakes for additional strength

Construct the leachate discharge pipe after strengthening the foundation

Pictures 1-2~4 Examples of improving soft foundations using wood stakes (Malaysia)

1-4 Considerations for rain water flow area

【Abstract】
In the “Fukuoka Method”, the landfill layer must be maintained in an aerobic state to the extent possible. Therefore, a structure where excess interstitial water can rapidly be removed from the landfill layer is needed. Higher amounts of excess interstitial water lead to higher loads on the leachate collection discharge pipe, leachate control pond, and surface liner and in addition costs associated with construction and maintenance control increase. From these points, it is desirable to choose a location where the amount of rainfall that flows into the landfill from surrounding areas is as small as possible.

【Explanation】

(1) Requirements

By maintaining excess interstitial water in the waste material, the spaces in the landfill layer become smaller causing rapid insufficiency of oxygen needed for aerobic decomposition causing an anaerobic condition. Therefore, in order to promote stabilization of aerobic decomposition of the landfill, excess water inside the landfill must be quickly removed in order to maintain a non-saturated condition. In the “Fukuoka Method” there is a simple structure that achieves this method but if there is a higher amount of rainwater that flows into the landfill layer, a construction with a proportionately higher number of leachate collection discharge pipes and gas venting pipes to remove the rain water is required.

Furthermore, the leachate control pond for controlling removed leachate must also increase in size.

In order to reduce construction costs and maintenance expenses, the smaller the amount of rain water that flows into the landfill area the better.

(2) Application Example

It is difficult to avoid rain water that falls directly on the landfill area in developing countries. Comparing landfill areas, as shown in Fig. 8, a method for reducing the rain water collection area include method of building up on a flat area, a method of levee widening of a hill, and a method of burying in a valley.

In order to properly control the landfill, rainwater removal structures must be installed in a configuration that won’t leak or break prior to starting the landfill and will cause increase in construction cost.

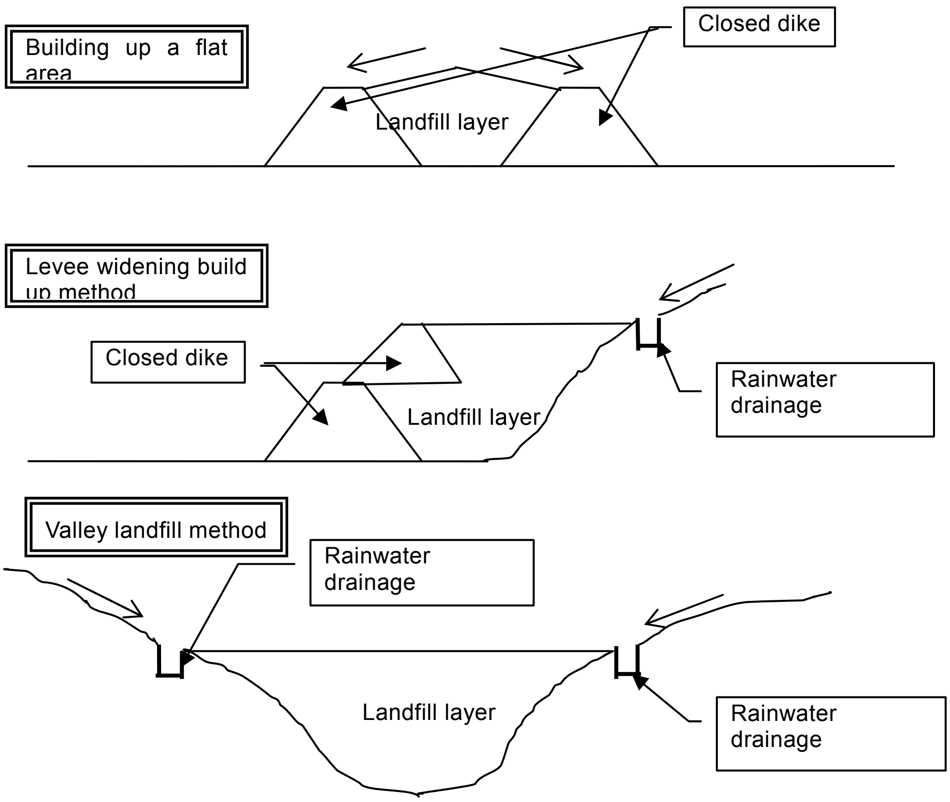


Fig. 1-8 Landfill shape and flow in of rainwater

２．Design and Construction Steps

2-1 Consideration of Construction Cost

【Abstract】
With regards to the final disposal design, the organization that will carry the burden of the construction costs and the financial condition of the organization that will perform maintenance control must be considered for determining the facility specification. The "Fukuoka Method" is a simple configuration and structure can be performed using various materials that can be obtained locally. With regards to design, it is necessary to use materials that can be obtained locally and easily, reduce construction cost to the extent possible, and make maintenance control easy.

【Explanation】

(1) Requirements

In general in developing countries a lot of costs are needed in the industrial base and to maintain the local infrastructure leaving insufficient funds for investment in waste management. Even in this type of condition, in order to maintain health and hygiene in cities, ensuring suitable final disposal sites is essential and while considering how to make construction costs of the final disposal site as low as possible, construction must continue.

(2) Application Example

The "Fukuoka Method" is a simple structure where it is possible to use materials that can be obtained locally and easily.

In Malaysia, bamboo has been used as the leachate collection pipe and this is shown in the picture 2-1. There are also examples of using waste barrels and waste tires as stand pipes (gas venting pipes). These are shown in pictures 2-2 ~ 2-5.

Picture 2-1 Example of using bamboo as leachate collection pipes

Picture 2-2 Example of using bricks as the leachate collection discharge pipe connection box material

Picture 2-3 Example of using waste tires as protection material for gas venting pipes

Picture 2-4 Example of using waste barrels as protection material for gas venting pipes

Picture 2-5 Example of using waste tires as leachate collection discharge pipes

2-2 Consideration for Maintenance Control Capability of Local Technicians

【Abstract】

In the “Fukuoka Method”, in addition to the progress status of the landfill, by raising leader type gas venting pipes and circulating leachate, functionality can be exhibited. However, if the raising of the leader type gas venting pipes is not easy, there are cases where the local technicians responsible for the landfill area can not provide suitable maintenance control.

Therefore, use of material that is easy to obtain and easy to use by the local technicians needs to be used at the design stage and a concrete manual needs to be prepared for maintenance control. If possible, it is desirable to implement training concerning landfill operation prior to starting up the landfill.

【Explanation】

(1) Requirements

In developing countries there are insufficient people to suitably control final disposal locations. Therefore, in order to make implementation at the site as easy as possible, while preparing equipment structure and usage materials, a manual that describes maintenance control that is easy to understand needs to be prepared to help the local technicians. If possible, it is desirable to perform training at the site regarding what is noted in the manual prior to starting the landfill.

2-3 Considerations for the leachate discharge pipe opening

【Abstract】

In order to achieve the “Fukuoka Method”, leachate collection discharge pipes and gas venting pipes must be installed to rapidly remove excess interstitial water and supply fresh air into the landfill layer. It follows that the leachate discharge pipe openings must continually be open to the atmosphere and therefore, even at the design stage, consideration is needed to make it simple to continually keep the leachate discharge pipe openings during the maintenance control stage.

【Explanation】

(1) Requirements

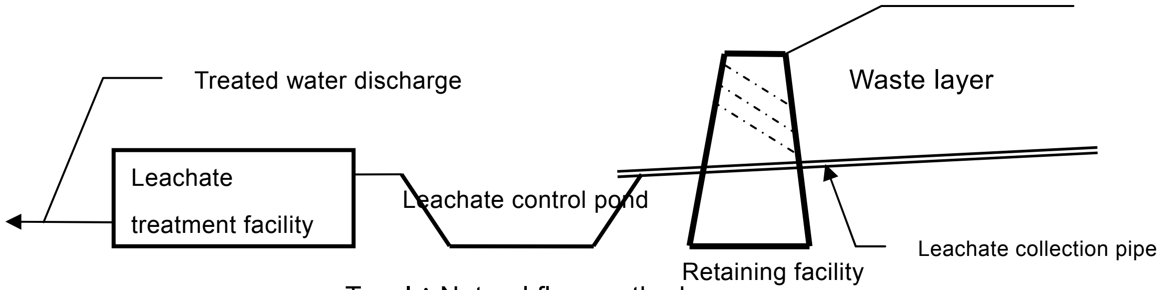
The “Fukuoka Method” is a method that uses a simple structure to maintain the landfill layer in an aerobic state to the extent possible, to stabilize the landfill and purify the leachate. Important points for maintaining the landfill layer in an aerobic state include installing leachate collection discharge pipes and gas venting pipes using a simple structure to in addition to quickly removing excess water, introduce air into the landfill layer. In order to implement this, the leachate discharge pipe openings must always be open to the atmosphere and consideration for easily maintaining this during the maintenance control stage must be taken in the design.

Picture 2-6 Example of leachate discharge pipe opening being submerged

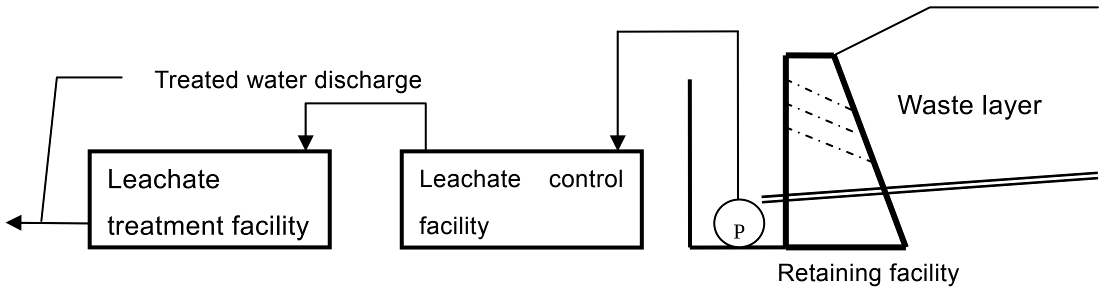
(2) Application Example

The structure shown in Fig. 2-1 below can be considered for the leachate discharge pipe opening. Comparing various structures enables summarization such as in Table 2-1. These examples are shown in pictures 2-7 ~ 2-8.

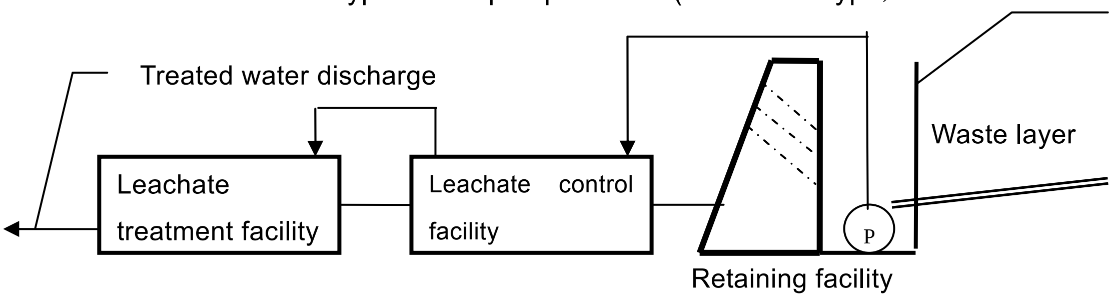
In developing countries, a leachate natural flow discharge method with simple maintenance and minimum expense is the best option.



TypeⅠ：Natural flow method



Type ：Pit-pump method (Out-of-site type）



Type ：Pit-pump method（Within site type）

図 2-1 Leachate removal method

Table 2-1 Comparison of leachate discharge pipe opening structures

	Construction costs	Operating expenses	Maintenance and control
Leachate natural flow discharge method	Small	Small (≅ 0)	Simple
Pit pump type (outside embankment)	Mid	Mid	Somewhat difficult
Pit pump type (inside embankment)	High	High	Difficult

Picture 2-7 Example of leachate discharge pipe opening that is appropriately opened (leachate natural flow discharge method)

Picture 2-8 Example of pit pump method

2-4 Considerations for ensuring capacity of leachate control pond

【Abstract】

In the “Fukuoka Method”, aerobic conditions must be maintained through rapid removal of excess water in the landfill layer. It follows that there needs to be sufficient capacity in the leachate control pond for controlling water removed leachate until it is treated.

【Explanation】

(1) Requirements

In conventional anaerobic landfill areas, as leachate was retained in the landfill area, from actual results, the amount of leachate requiring control was smaller compared to that required when using the “Fukuoka Method”. However, when using the “Fukuoka Method”, as rapid removal of excess water inside the landfill layer is required, forecast of the amount of leachate that will be generated must be performed and using a tank model, leachate treatment capacity and leachate control pond capacity must be ensured.

(2) Application Example

In the “Fukuoka Method” (semi anaerobic landfill structure) case, leachate generated can be forecast using a prediction formula with consideration for a rational equation and time delay in general; however, in the case of developing countries, there is generally insufficient data so using a simple rational method is appropriate.

The sanitary landfill level of the final disposal area can be classified in 4 steps using the facilities and equipment of the landfill area or the operation control method (refer to table 2-2) and selection of forecast method based on this level is preferred.

In the case of level 1 or level 2, leachate is discharged without treatment and therefore, from a concept perspective, a leachate control pond is not needed but in the case that the amount of leachate is small, it can be considered that through retaining leachate in a leachate control pond that is sufficiently large that the leachate will evaporate away. Therefore, it is desirable to consider evapotranspiration when calculating the capacity of the leachate control pond.

In the case of level 3 where a circulation system is introduced, the capacity of the leachate control pond is calculated using a simple method based on a rational expression.

If setting up level 4 (refer to table 2-2) or above leachate treatment, calculate the required capacity of the leachate control pond using the tank model.

Table 2-2 Sanitary landfill levels

Primary operation method, facility	Level 1	Level 2	Level 3	Level 4
Control facility	○	○	○	○
Weight measuring of waste brought in	○	○	○	○
Enclosing bunds		○	○	○
Buffer zone		○	○	○
Landfill machinery	○	○	○	○
Daily soil covering, gas venting		○	○	○
Approach and 0n-site roads	○	○	○	○
Leachate circulating system			○	○
Leachate treatment				○
Seepage control works				○
Moveable fence for littering preventing			○	○

Quote: “Supporting Capacity Development for Solid Waste Management in Developing Countries” Table 2-17 JICA, 2004.11. (portion corrected)

2-5 Considerations for ensuring leachate collection discharge capacity

【Abstract】
In the “Fukuoka Method”, installing leachate collection discharge pipes suitably in the bottom of the landfill area that rapidly discharge leachate in the landfill area and in addition introduces fresh air into the landfill through natural convection and thus supplying air promotes aerobic decomposition in the landfill layer. It follows that in order to rapidly remove leachate from the landfill area, the bottom of the landfill area must be formed into a gradient towards the leachate discharge pipe opening. Therefore, the construction form and gradient of the bottom must be suitably set forth at the design stage.

【Explanation】

(1) Requirements

There is the possibility that the bottom of the landfill area will deform depending on the shape of the landfill area and the foundation conditions. While leachate flows out of the leachate discharge pipe opening, in actuality, a large portion flows under the crushed rock that protects the circumference of the leachate collection discharge pipe inside the landfill area and flows into the leachate discharge pipe at the lowest flow area inside the landfill area and flows out of the leachate discharge pipe opening. Therefore, ensuring of a suitable gradient for the bottom of the landfill area is important for ensuring leachate collection discharge capacity. With regards to design, the foundation conditions of the landfill area must be investigated and the shape of the bottom and constructed gradient must be determined so that a reverse gradient of the bottom of the landfill area (case I in Fig. 2-2) and a depression shape (case II in Fig. 2-2) do not occur.

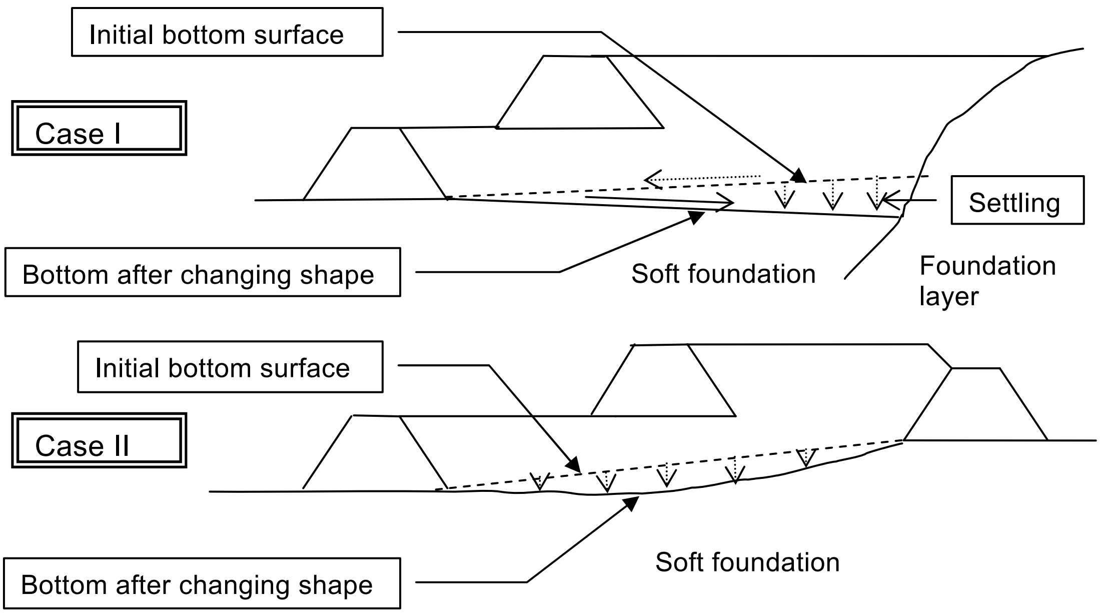
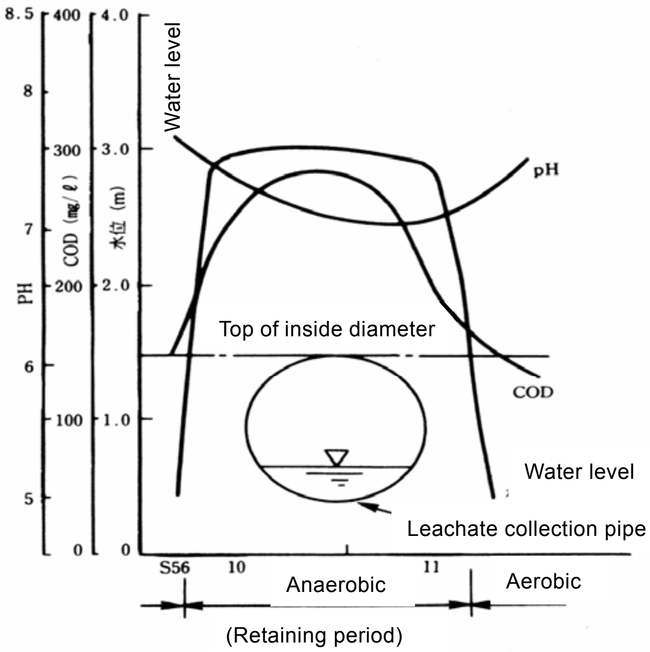


Fig. 2-2 Defect of the leachate discharge pipe gradient due to settling of foundation



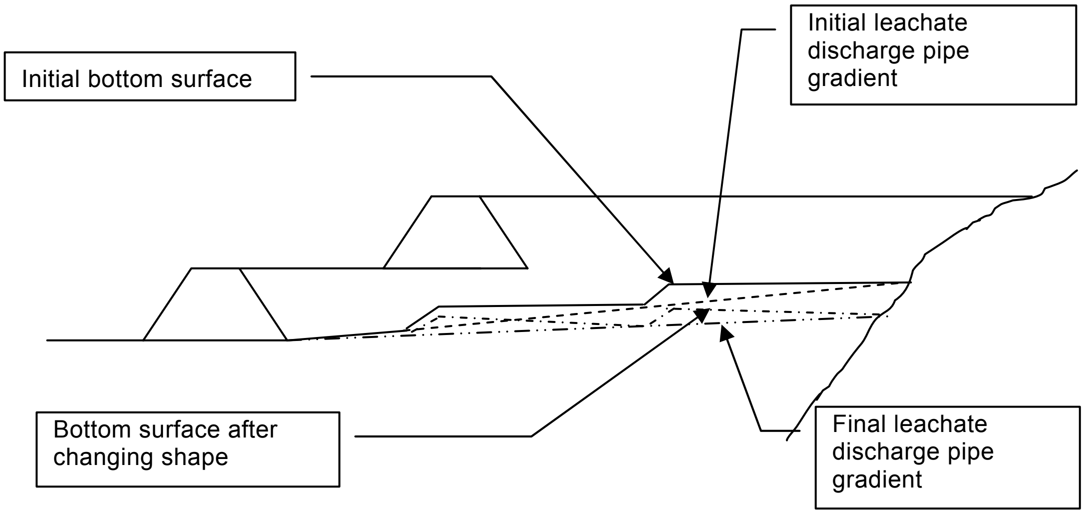
Source: Hydraulic Sanitary Engineering Laboratory, Department of Civil Engineering, Fukuoka University

Fig.2-3 Change of leachate quality with retaining time

If the leachate ceases to flow out of the leachate discharge pipe opening and leachate pools up in the landfill area, air stops flowing into the landfill area through the leachate collection discharge pipe openings and as a result, as shown in Fig. 2-3, COD worsens, pH goes down and stabilization of the landfill area is delayed.

(2) Application Example

As a countermeasure, setting of the gradient of the bottom at roughly 3% considering deformation of the bottom surface after completion of the landfill or constructing the bottom of the landfill area in a step shape with the leachate collection discharge pipe area having a steep gradient (roughly 3 ~ 6%) can be considered. Incidentally, when setting the gradient of the bottom, consideration must be taken to prevent changing the shape of the slip plane of the bottom surface that would cause a landslide of the entire landfill area. This is especially important if a seal sheet is laid out on the bottom surface.



*After deformation the leachate flows upstream on the bottom surface and collects into the leachate collection discharge pipes from the horizontal gradient and from the gradient of the leachate collection pipe, flows downstream and is discharge.

Fig. 2-4 Countermeasure for settling of foundation

2-6 Considerations for ensuring cross section of leachate collection discharge pipe

【Abstract】
In the “Fukuoka Method”, installing leachate collection discharge pipes suitably in the bottom of the landfill area rapidly discharges leachate in the landfill area and in addition introduces fresh air into the landfill through natural convection and thus supplying air promotes aerobic decomposition in the landfill layer. Therefore, it is necessary to ensure a cross section of the leachate collection discharge pipe enabling smooth influx of air into the landfill area.
Therefore, in the “Fukuoka Method”, the pipe diameter of the main leachate collection discharge pipe is recommended to be at least 600 mm. In order to achieve the effects of the “Fukuoka Method” this needs to be a minimum of at least 450 mm.

【Explanation】

(1) Requirements

Leachate collection discharge pipes are set in the bottom of the land fill area and maintenance control after starting the landfill is difficult. As an obstacle for air inflow cross section of the leachate collection discharge pipe, retention of leachate inside the leachate collection discharge pipe covering a large portion of the cross section or collecting of filthy water in the bottom of the leachate collection discharge pipe and blocking the cross section can occur. These types of things are difficult to estimate beforehand during the design stage. Therefore, from experience, it is desirable to use a pipe diameter of at least 600 mm for the leachate collection discharge pipe when using the “Fukuoka Method”. However, when using pipe materials that can be obtained in developing countries, the larger the pipe the more there is anxiety regarding the strength of the pipe. In this case, uses a pipe diameter of 450 mm for the main leachate collection discharge pipe and use a design with several of these placed as in Fig. 2-5.

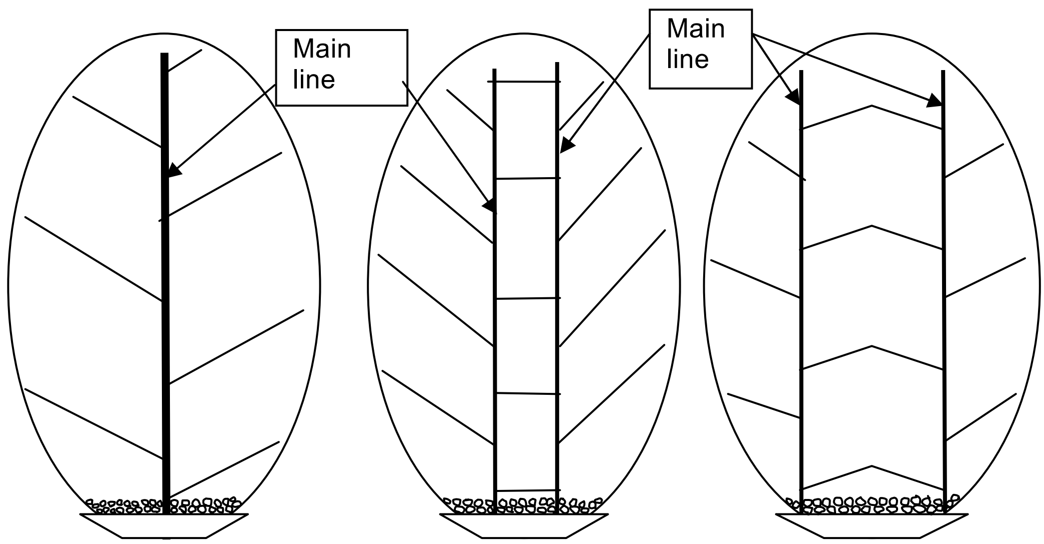


Fig. 2-5 Placement pattern for leachate collection discharge pipes

(2) Application Example

In two final disposal areas in Fukuoka-shi, there are different configurations of the leachate collection discharge pipes as shown in pictures 2-9, 2-10.

Picture 2-9 Placement example of leachate collection discharge pipes at Fukuoka-shi Busetsugaura Landfill

Picture 2-10 Placement example of leachate collection discharge pipes at Fukuoka-shi, Nakata Landfill

2-7 Considerations for ensuring height of leachate collection discharge pipe and covering material

【Abstract】

In the “Fukuoka Method”, in order to introduce fresh air into the landfill through the leachate collection discharge pipes, it is necessary to ensure a cross section enabling air flow in leachate collection discharge pipes is open at all times. Therefore, it is necessary to complete a design where not more than 1/3 of the diameter of the leachate collection discharge pipes is buried lower than the bottom of the landfill area.

【Explanation】

(1) Requirements

In the “Fukuoka Method”, fresh air must be introduced into the landfill through the leachate collection discharge pipes. However, in the examples so far, the leachate collection discharge pipe are laid deep in trenches that have been dug and there are cases where in the event that leachate is retained in the landfill area, the cross section for air flow is completely blocked off.

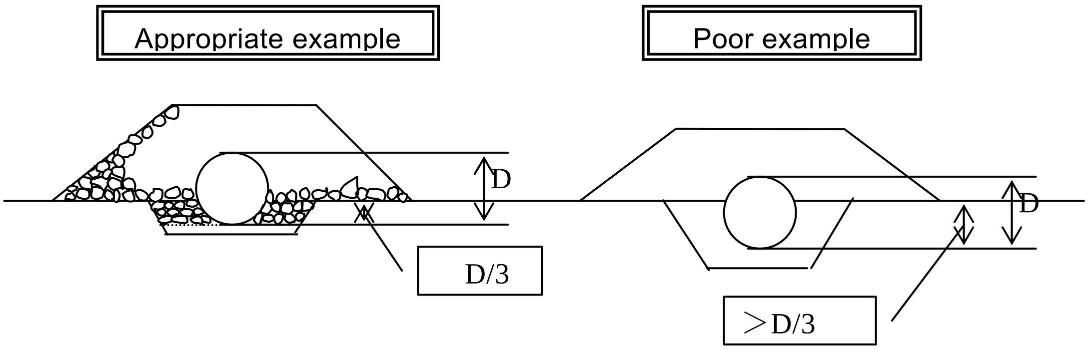
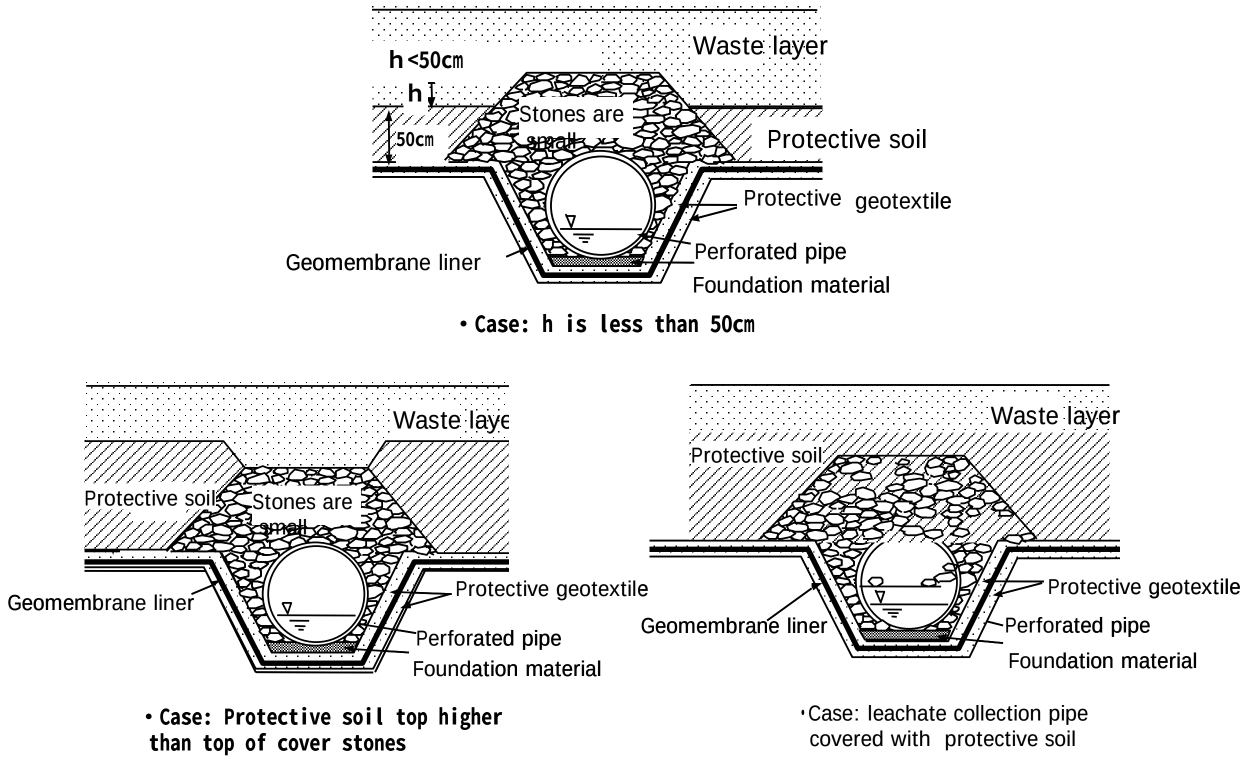


Fig. 2-6 Placement examples of leachate collection discharge pipes

(1) It is easy for the leachate collection discharge pipe to become submerged if water is retained in the landfill
(2) Infiltration of sludge becomes easier

Picture2-11 Good example of leachate collection facilities

Picture 2-12 Good example of main leachate collection pipe



Source: Fukuoka University

Fig. 2-7 Bad example of main leachate collection pipe

(2) Application Example

As a method for ensuring the height of the leachate pipes, the improved structure as in Fig. 2-8 in consideration for constraints of laying the sealant sheet can be used.

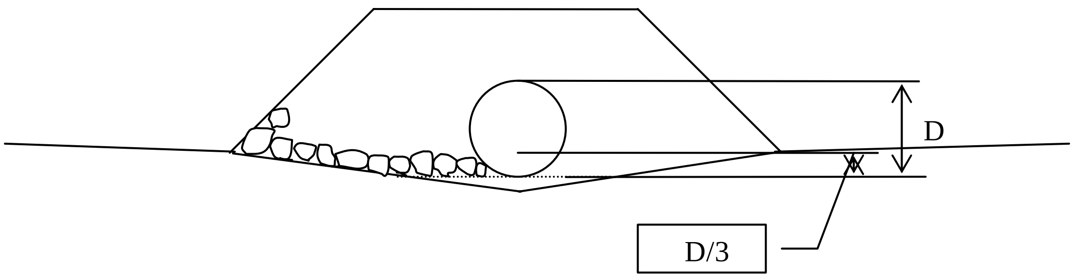
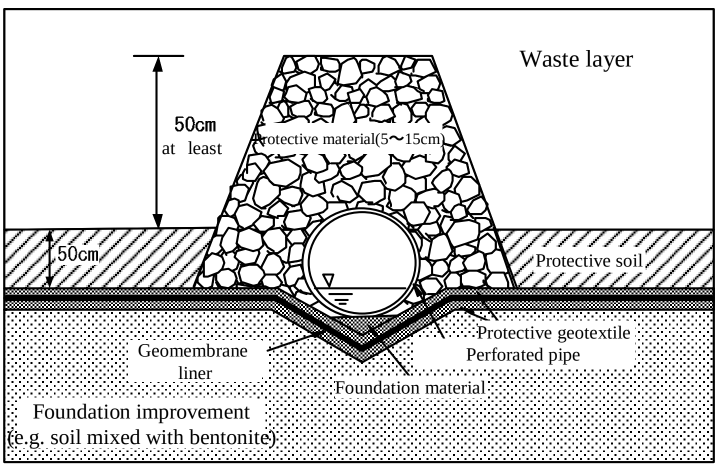


Fig. 2-8 Improvement example for placement of water seepage collection discharge pipe



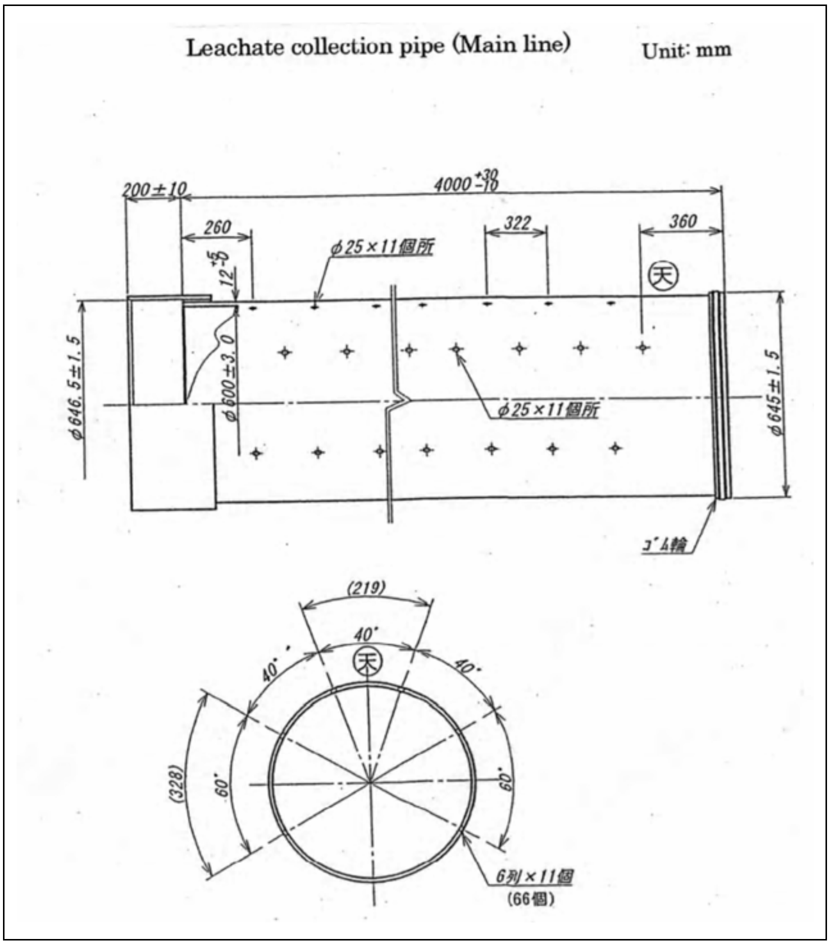
2-8 Considerations for ensuring perforated areas in the leachate collection discharge pipe

【Abstract】
In the “Fukuoka Method”, fresh air must be introduced into the landfill through the leachate collection discharge pipes. Air is supplied to the landfill layer through holes opened in the leachate collection discharge pipes. Therefore, care must be taken to prevent these holes from being plugged. This can be achieved from suitably setting the configuration of the leachate collection discharge pipes at the design stage.

【Explanation】

(1) Requirements

In the “Fukuoka Method”, fresh air must be introduced into the landfill through the leachate collection discharge pipes. Supply of air to the landfill layer through the leachate collection discharge pipe is provided through holes in the leachate collection discharge pipes. Therefore, measures must be taken so that the perforations of the leachate collection discharge pipe exhibit their function.



Picture 2-9 Example of perforations in leachate collection discharge pipes

(2) Application Example

The good example or counter example configuration shown in chapter 2-6 must be used to achieve ensuring that the holes in the leachate collection discharge pipes stay open. Comparing these, the countermeasure example of Fig. 2-8 has less chance of the perforations being blocked by sludge etc.

Picture 2-13 Suitable placement example for ensuring perforation areas stay open

2-9 Considerations for reliable protection of leachate collection discharge pipes

【Abstract】

Like gas venting pipes, leachate collection discharge pipes are key equipment in the "Fukuoka Method". As this equipment can not be maintained or controlled after the landfill is started, they need to be designed such that they are not broken in conjunction with use of the landfill and they also need to have good protection set up during the construction stage.

【Explanation】

(1) Requirements

In the "Fukuoka Method", installing leachate collection discharge pipes suitably in the bottom of the landfill area rapidly discharges leachate in the landfill area and in addition causes fresh air to flow into the landfill through natural convection and thus supplying of air promotes aerobic decomposition in the landfill layer. Therefore, as the leachate collection discharge pipes are key equipment in the "Fukuoka Method", they must be suitably protected so that they are not damaged through operation of the landfill or pressure caused by landfill waste.

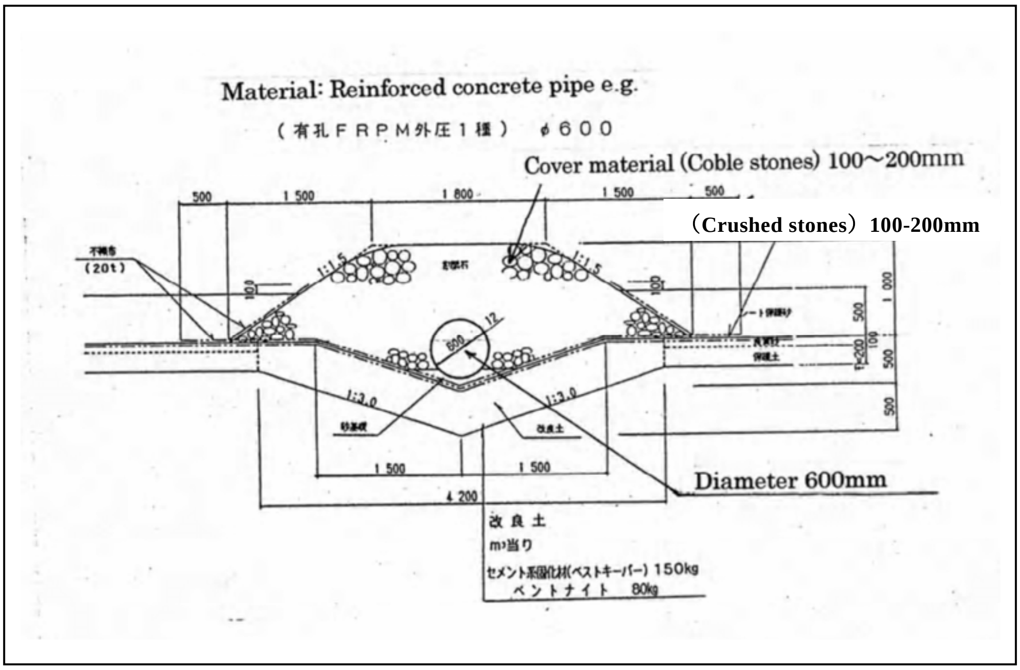


Fig. 2-10 Leachate collection discharge pipe standard cross section diagram

(2) Application Example

At the Nakata landfill in Fukuoka-shi, configuration is determined following the standard cross section of Fig. 2-10 as shown in pictures 2-11 and 2-12.

2-10 Considerations for reliable installation of gas venting pipes

【Abstract】
The “Fukuoka Method” is a method that promotes decomposition of organic material inside the landfill layer through introduction of fresh air into the landfill layer and this can not be achieved by simply installing leachate collection discharge pipes. This is that discharging of gas in the landfill layer warmed by heat generated through decomposition of organic material through gas venting pipes to the top of the landfill pulls fresh air through leachate discharge pipe openings based on convection. Therefore, gas venting pipes must be suitably placed and reliably installed in the landfill area.

【Explanation】

(1) Requirements

In the “Fukuoka Method”, it is necessary to enable maintaining of the landfill layer in an aerobic environment. It follows that it is necessary to place gas venting pipes in the landfill area at suitable intervals.

In order to reliably install gas venting pipes, the configuration for raising the gas venting pipes must use materials that can be obtained locally to the landfill site and use a configuration that can be implemented using the control structure at the landfill site.

In cases where there is a lot of organic material that can be decomposed in the landfill waste and the landfill layer is at optimal aerobic decomposition conditions, the oxygen in the landfill layer will be rapidly consumed and may switch to anaerobic. In this case, in order to smoothly introduce fresh air into the landfill layer, air flow pipes must be placed every 10 ~ 15 m of height of the landfill. (See Fig. 2-12)

The roles and purposes of the vertical gas venting pipes are as follows.

(i) Suppress generation of CH4 through expanding aerobic area
(ii) Rapid removal of leachate function
(iii) Circulation of leachate using vertical gas venting pipes

(2) Application Example

In the “Fukuoka Method”, it is recommended that gas venting pipes be installed every 20 to 40 m for flat landfill sites. If the landfill layer thickness is less than 10 m, a 40 m interval is suitable, if the landfill layer thickness is 10 m to 20 m, use a 30 m interval and if more than this, an interval of 20 m is suitable. Using an interval of less than 20 m enables increased aerobic decomposition but as the gas venting pipes would hinder landfill operation, this can not be recommended.

In cases where the amount of material requiring placement in the landfill is high, large number of gas venting pipes impede landfill operation and also become complex to erect. In this case, by taking into account installation of horizontal air flow pipes every 15 m of waste landfill layer, the installation interval can be widened to roughly 40 m.

In order to ensure reliable installation of gas venting pipes, it is necessary to use materials that can be obtained at the site and a configuration that can easily be implemented. The material noted in chapter 2-1 can be used as an example.

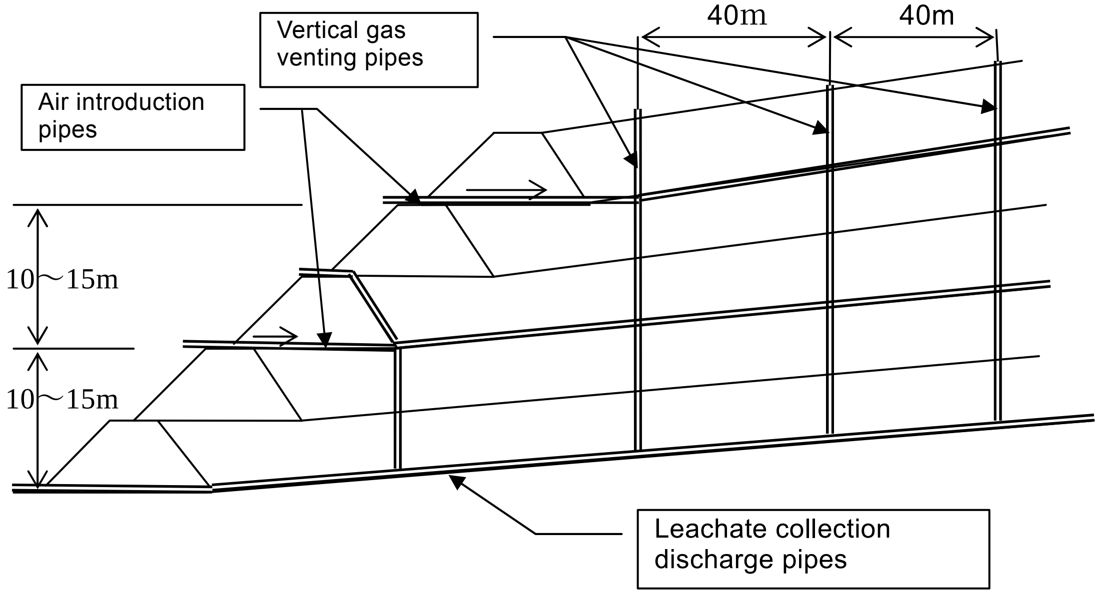
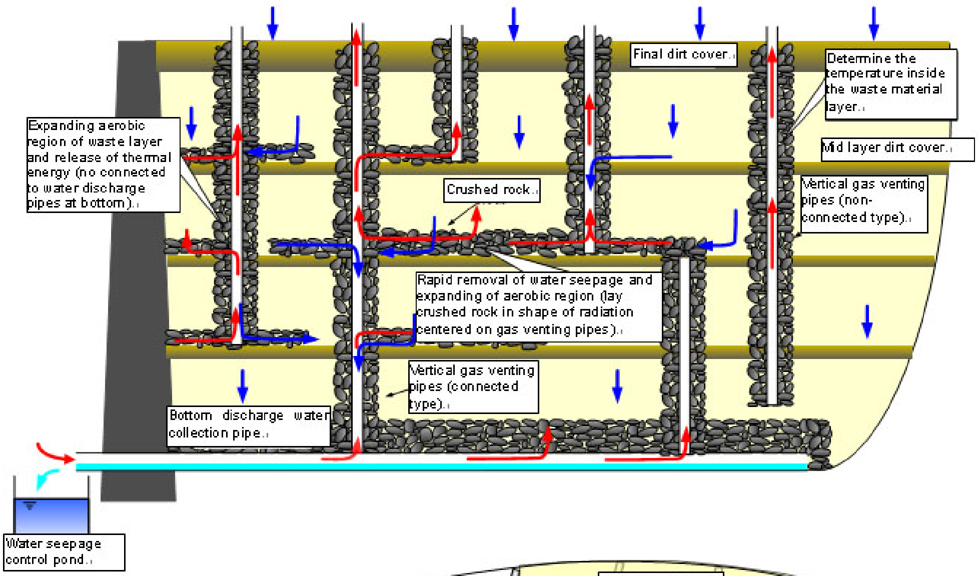
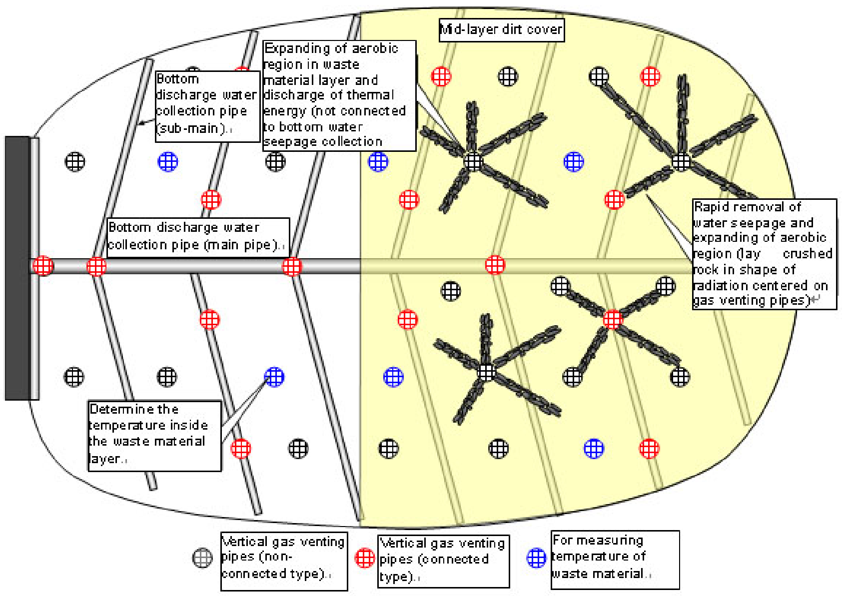


Fig. 2-12 Illustration of application of air introduction pipes in the case that the landfill height is high

Picture 2-15 Installation example of gas venting pipes

In the case that there is not a slope where gas introduction pipes can be installed, suitably forming of a layer of crushed rock enabling supplying of air from the vertical gas venting pipes into the landfill layer can be considered as a countermeasure. An illustration of this countermeasure is shown in the following diagrams.


Final dirt cover
Determine the temperature inside the waste material layer
Mid layer dirt cover
Vertical gas venting pipes (non-connected type)
Expanding aerobic region of waste layer and release of thermal energy (no connected to water discharge pipes at bottom)
Crushed rock
Rapid removal of water seepage and expanding of aerobic region (lay crushed rock in shape of radiation centered on gas venting pipes)
Vertical gas venting pipes (connected type)
Bottom discharge water collection pipe
Water seepage control pond


Mid-layer dirt cover
Expanding of aerobic region in waste material layer and discharge of thermal energy (not connected to bottom water seepage collection
Bottom discharge water collection pipe (sub-main)
Bottom discharge water collection pipe (main pipe)
Rapid removal of water seepage and expanding of aerobic region (lay crushed rock in shape of radiation centered on gas venting pipes)
Determine the temperature inside the waste material layer
Vertical gas venting pipes (non-connected type)
Vertical gas venting pipes (connected type)
For measuring temperature of waste material

2-11 Considerations for sufficient protection around gas venting pipes

【Abstract】

The “Fukuoka Method” is a method that promotes decomposition of organic material inside the landfill layer through introduction of fresh air into the landfill layer and this can not be achieved by simply installing leachate collection discharge pipes. This is that discharging of gas in the landfill layer warmed by heat generated through decomposition of organic material through gas venting pipes to the top of the landfill pulls fresh air through leachate discharge pipe openings based on convection. Therefore, use of a configuration with sufficient consideration for protecting around the gas venting pipes to enable maintaining of the function of the gas venting pipes is necessary.

【Explanation】

(1) Requirements

The “Fukuoka Method” is a method that promotes decomposition of organic material inside the landfill layer through introduction of fresh air into the landfill layer and this can not be achieved by simply installing leachate collection discharge pipes. This is that discharging of gas in the landfill layer warmed by heat generated through decomposition of organic material through gas venting pipes to the top of the landfill pulls fresh air through leachate discharge pipe openings based on convection.

In general, the function of gas venting pipes are not understood in developing countries and they are installed in an inappropriate manner, leading to cases where the function of the “Fukuoka Method” is lost. It follows that protection of the gas venting pipes must be clearly shown in the drawings during the design stage and the installation procedure must be specified.

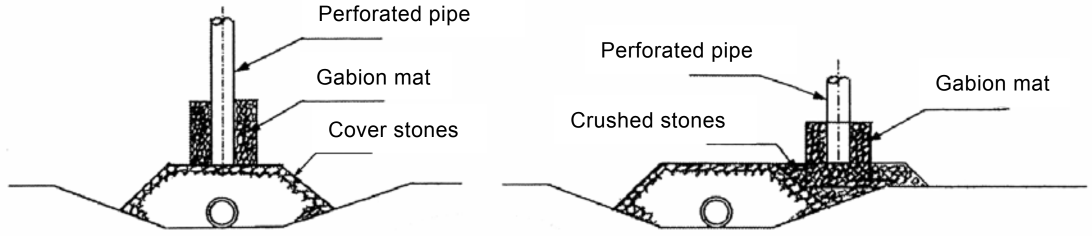


Fig.2-13 Structure example of gas venting pipe

Picture2-16 Example of bottom leachate collection pipe and gas venting pipe

(2) Application Example

In the "Fukuoka Method", for protection of the gas venting pipes, it is desirable that the dimensions shown in Fig. 2-14 below are used as a basis and that structure is determined based on actual conditions for developing countries and each landfill site.

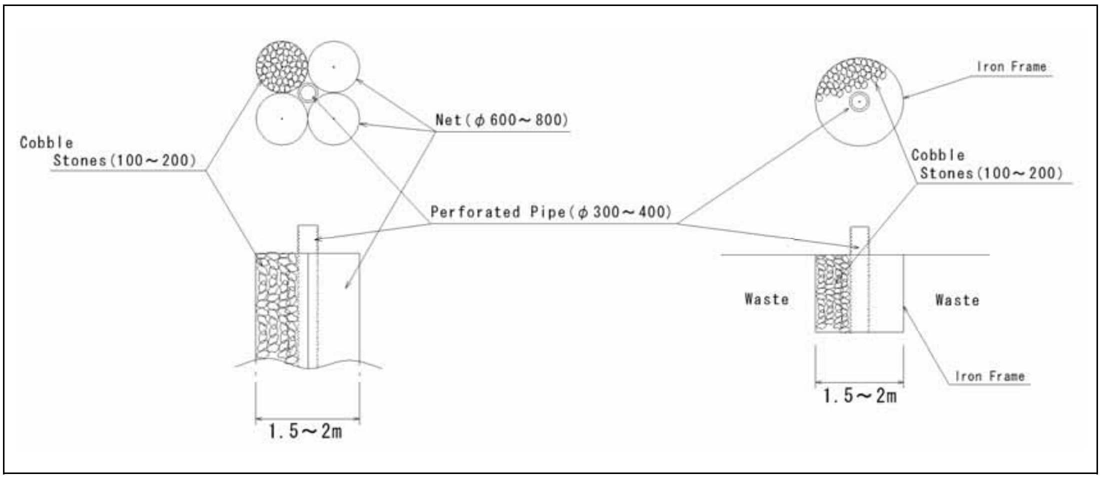


Fig. 2-14 Gas venting pipe production standard dimensions

2-12 Considerations for landfill height and feasibility of leachate circulation

【Abstract】
The “Fukuoka Method” is a configuration with a better purification function for the landfill layer. It follows that saturation of the landfill layer again using leachate that has been discharged has the effect of improved purification. In a landfill where a level 3 or better leachate treatment facility is not installed, use of this method is effective at improving protection of the environment and establishing the capability of the pump based on the financial condition of the site and setting the height enabling circulation of leachate from the bottom most flow point of the landfill site is desirable.

【Explanation】

(1) Requirements

As the “Fukuoka Method” is called a semi-aerobic landfill, there are also areas that are anaerobic in addition to the aerobic areas and while decomposition of biological pollution material proceeds in the aerobic areas, the combination of both aerobic and anaerobic areas has the function of nitrogen removal treatment. As the nitrogen is removed from the leachate, the nitrogen in the leachate has to go through the process of being oxidized and reduced but through saturating the landfill layer with leachate that has been discharged again, this function can be utilized to its utmost.

In the “Fukuoka Method”, circulating leachate by returning leachate discharged from the landfill site back to the landfill site is effective at both purifying the water quality of the leachate and reducing the amount of leachate. Circulation of leachate can be achieved using a simple system. If introduction of leachate treatment equipment is difficult from a financial perspective, use of circulation is desirable. Furthermore, in the case that introduction of leachate treatment equipment is feasible, this reduces the load on the leachate treatment equipment and suppresses treatment costs and use is therefore desirable. However, circulation requires a pump to return leachate to the landfill area.

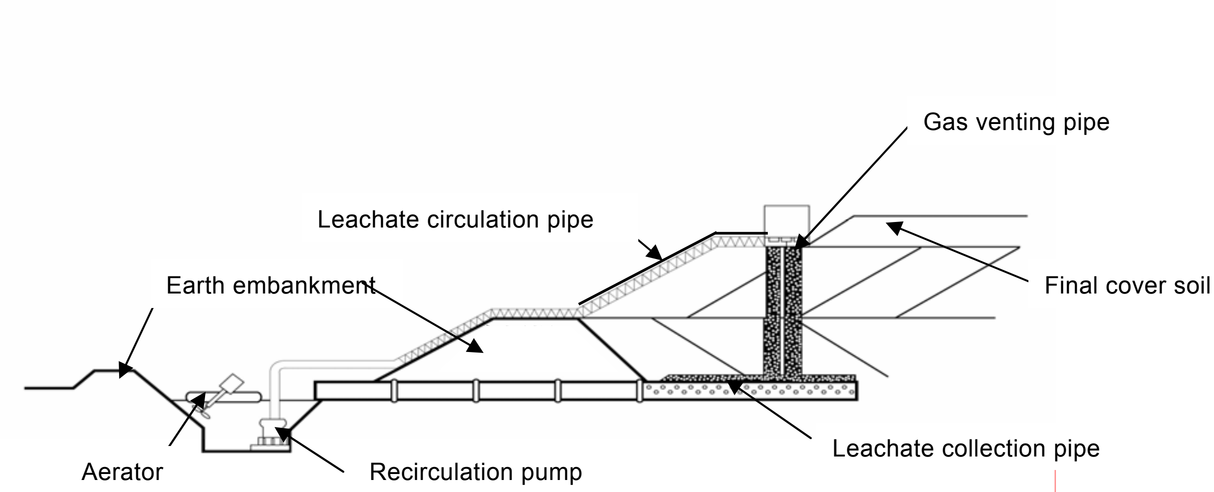


Fig. 2-15 Example of Ampang Jajar landfill site in Malaysia that uses a water seepage circulation system

(2) Application Example

A picture of the Malaysia Ampang Jajar landfill site example is shown below. In addition an example of the Samoa Tafaigata landfill site is shown in picture 3-11.

Picture 2-17 Example of Malaysia Ampang Jajar landfill site


Picture 2-18 Example of Japan Hashimoto Landfill site

3. Landfill operation

3-1 Considerations for maintaining function of the leachate collection discharge pipes

【Abstract】

In the Fukuoka Method, the leachate collection discharge pipes are important facility for supplying air, removing leachate and maintaining an aerobic environment. The leachate discharge pipes must be protected from loads that occur during landfill operation and consideration must be taken concerning the type of waste disposed of to prevent loss or reduction in function during the landfill operation stage and care must be taken to enable maintaining the leachate collection discharge pipe discharge opening open to the atmosphere.

【Explanation】

(1) Requirements

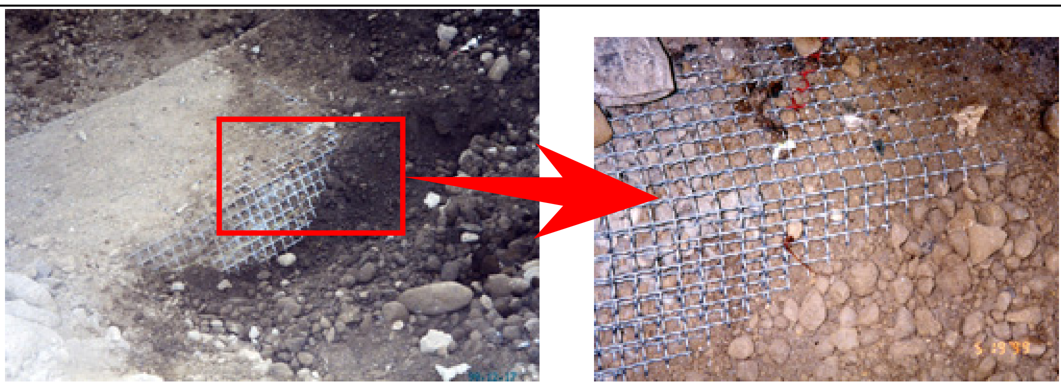
The Fukuoka Method (semi anaerobic structure) has (1) leachate collection discharge pipes installed in the bottom, and (2) gas venting facilities as facility for supplying air (oxygen) to the waste layer. Of these, the leachate collection discharge pipes have the most important role and things that would reduce their function such as breakage or blockage of the pipes must be completely avoided. Therefore, sufficient care must be taken during landfill operation to maintain the functionality of the leachate collection discharge pipes.

(2) Application Example

(i) Consideration for type of waste material disposed of near the leachate collection discharge pipes. (Avoid small particle shaped items that can easily wash away.)

During use of the landfill, there is the possibility that the filter material of the leachate collection discharge pipes that are installed at the bottom of the landfill will become plugged with small particles in the soil covering and waste materials as well as insoluble materials included in the leachate. (See Fig. 3-1)

Especially when the first layer is buried, soil covering material and waste particles that flow with rain water may flow into the filter material at locations where the leachate collection discharge pipes are directly exposed and plug the filter material. Furthermore, the filter material may be plugged by non-soluble materials included in the leachate that is generated through decomposition of waste that is being processed in the landfill.



Picture 3-1 Plugging of leachate collection discharge pipes

The function of the leachate collection discharge pipes must be maintained over the long period of time unit the disposal site is closed. It follows that when land filling close to the leachate collection discharge pipes, that care must be taken to suppress clogging of the filter material.

One method for doing this is to avoid particles that can flow easily as landfill waste in the vicinity of the leachate collection discharge pipes and instead fill with bulky waste materials that have non-uniform shape and are rough and that are not soluble such as rubble from construction materials and pieces of concrete. (See Picture 3-2 ~ 3)

Picture 3-2 Example of landfill of large waste material in the vicinity of leachate collection discharge pipes

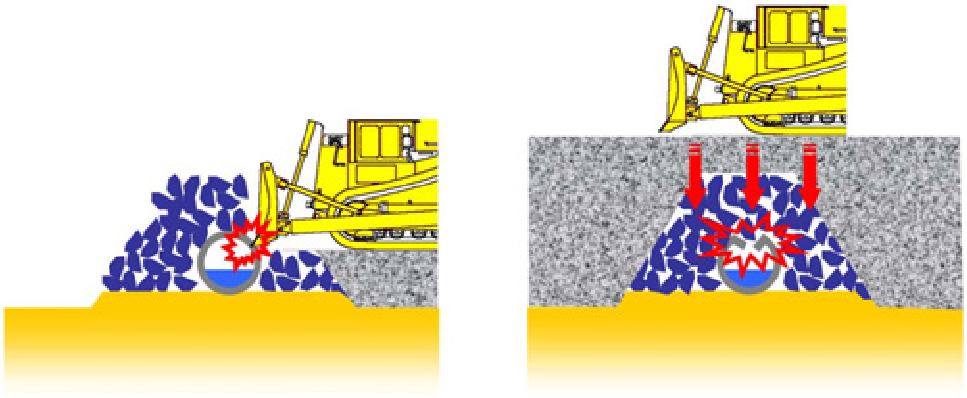
Picture 3-3 Example of landfill of rough waste material in the vicinity of leachate collection discharge pipe

(ii) Landfill method that does not break the leachate collection discharge pipes

The leachate collection discharge pipes installed on the bottom must be designed with the strength to withstand the static weight of waste layers of landfill up to the height planned for the landfill. However, initially when the landfill thickness is less than 3 m, the pipes directly receive the kinetic force of transport vehicles and heavy machinery driving over the surface of the landfill area. Furthermore, as the leachate collection discharge pipes are exposed for the first layer, heavy machinery used for landfill operation may directly contact the leachate collection discharge pipes and cause damage. If the leachate collection discharge pipes are damaged, waste material may get into the pipe directly at the damaged location and hinder flow of leachate and/or supply of air. (See Fig. 3-1)

Therefore, in the early stages of landfill where there is less than 3 m, suitable measures must be taken when driving heavy landfill machinery or transport vehicles over the top of the leachate collection discharge pipes.

One method of preventing damage to leachate collection discharge pipes is to maintain a landfill thickness of crushed rock that is not affected by kinetic load of heavy machinery of at least 1 m and proceed with the landfill for the first layer.



(a) Damage due to contact with heavy machinery (b) Damage due to kinetic load of heavy machinery

Fig. 3-1 Damage phenomenon of leachate collection discharge pipes of the initial layers of landfill

In cases where sufficient landfill thickness can not be maintained or locations where heavy machinery or large vehicles cross frequently, lay a steel plate with a thickness of at least 20 mm with the purpose of distributing the kinetic load of the heavy machinery etc. (see Fig. 3-2) or use a special road with at least 1 m of fill for crossing to prevent damage of leachate collection discharge pipes.

(iii) Control of the leachate level (pipe end open at all times)

The Fukuoka Method mechanism uses decomposition thermal energy to introduce fresh air (oxygen) through the discharge opening of the leachate collection discharge pipes in the bottom and enables supply of oxygen to the waste layer through the leachate collection discharge pipes and gas venting pipes. Therefore, the water level of the leachate control pond must be controlled and the discharge pipe opening of the leachate collection discharge pipes must be open to the atmosphere at all times.

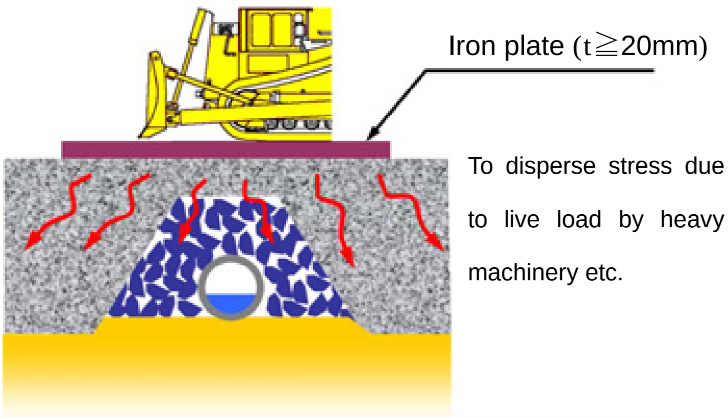


Fig.3-2 Example of measure to protect leachate collection pipe in case of thin first waste layer

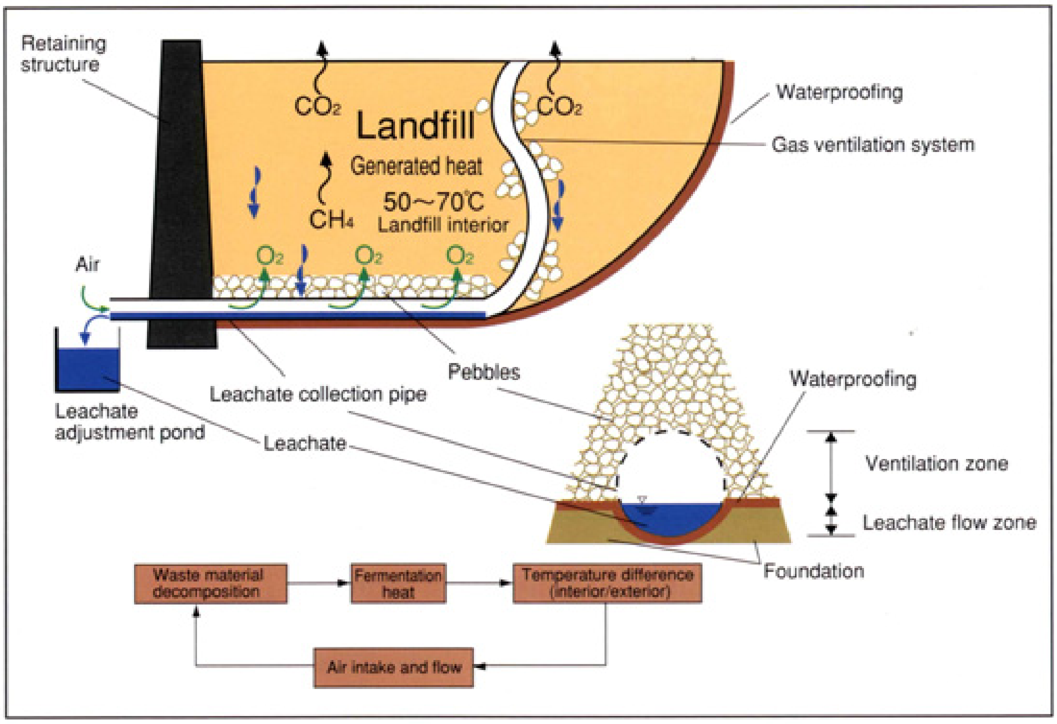


Fig. 3-3 Fukuoka Method configuration illustrative diagram

Fig. 3-3 is an illustrative diagram of the landfill configuration using the Fukuoka Method. As shown in this diagram, fresh air that flows into the leachate collection discharge pipes in the Fukuoka Method configuration is supplied to the waste layers through convection. Therefore, this function stops working if the pipe openings of the leachate collection discharge pipes are not open to the atmosphere at all times, and ill effects such as the waste layer becoming anaerobic, reducing of waste decomposition, generation of toxic gas and reduction in the quality of the leachate occur.

In order to prevent these effects, the water level of the leachate control pond that is at the opening of the pipe must be controlled at all times and the opening of the pipes must be open to the atmosphere at all times.

3-2 Considerations for maintaining the function of the gas venting facility

【Abstract】

Gas venting facilities are important structures for the supply of air (oxygen) to the waste landfill layer. Therefore, installation methods and protection during the landfill operation stage must be sufficiently considered.

【Explanation】

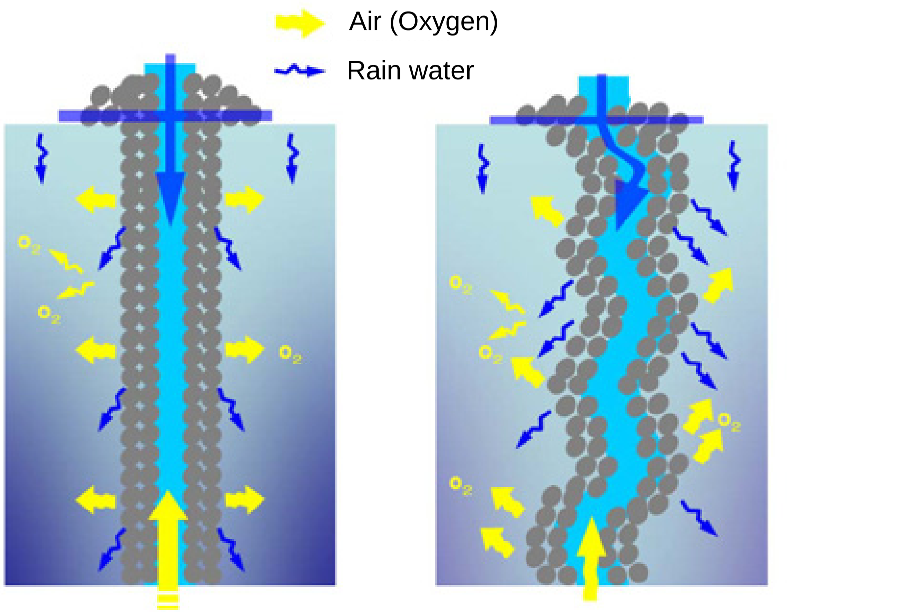
(1) Requirements

Gas venting facility is important facility that enables smooth flow of air so that air in the landfill layer is not insufficient in the case that there is a lot of organic material to be decomposed. Therefore, maintaining of the function of the gas venting facility with regards to landfill operation must be sufficient considered.

(2) Support Example

(i)Vertical pipes (gas venting facility) reliable, suitable installation. (Meandering is better)

In the Fukuoka Method (semi-aerobic structure), leachate collection discharge pipe on the bottom and vertical pipes (gas venting facility) are important facilities that have the function of promoting discharge of leachate and supplying air (oxygen).Therefore, it is necessary to install the vertical pipes (gas venting facility) in suitable locations and to reliably connect and raise them in conjunction with proceeding of the waste landfill.



（a） Case of raising straight （b） Case of raising in a meandering manner

Fig. 3-4 Supply of oxygen through the gas venting facilities (image diagram)

In order to more fully exhibit efficiency in the function of the vertical pipes, it is desirable to link the vertical pipes directly to the leachate collection discharge pipes and install them roughly with a horizontal distance of roughly 20 m. Furthermore, in order to ensure better contact surface and suppress plugging of the vertical pipes at the same time, they should have a diameter of at least 10 cm and in addition be covered with at least 1 m in diameter of filter material that is not soluble.

Furthermore, in the case that the vertical pipes are raised (connected) along with the increasing height of the waste layer, use the same type of filter material and same diameter for raising of the vertical pipes. In this manner, the vertical pipes are not raised in a straight line; it is more desirable for them to meander. This configuration enables sufficient retention time of air and rainwater inside the gas venting facility and promotes supplying of oxygen. (See Fig. 3-4)

As a method for raising the gas venting facility while causing it to meander, connect and raise the system based on the following elements (see Fig. 3-5).

a) Install the gas venting pipe at an inclination as in Fig. 3-5 and fill with crushed rock as the gas venting facility for each waste layer.

b) When connecting and raising the next layer, install the gas venting facility centered on the center of the gas venting pipe that is above the surface and install the gas venting pipe in a direction that is different from the previous layer and fill with crushed rock.

c) Repeating i) and ii) will enable raising the gas venting pipe in a meandering path.

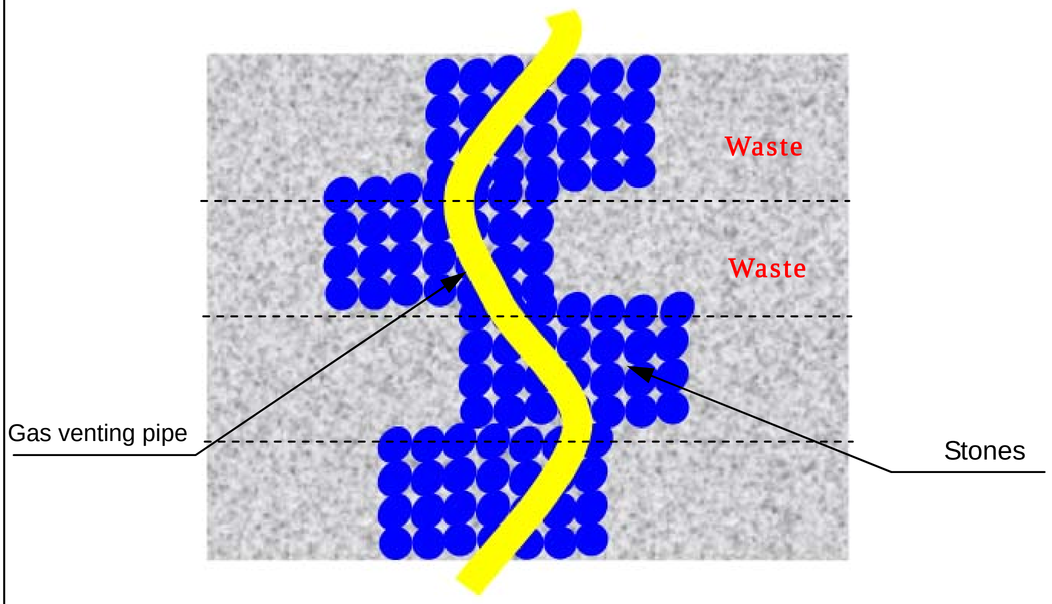


Fig. 3 – 5 Implementation example of raising in a meandering manner

(ii) Landfill method that does not break gas venting facilities

When performing landfill operations, vertical pipes can be knocked down, broken, or collapse due to contact with heavy machinery or load of landfill material; therefore, care is important when performing landfill operations.

For starting of the landfill for each layer, in general the vertical pipes and sloped surfaces for gas venting facilities target that for 1 layer (roughly 3 m). In this condition, if waste pushes from one side or contact is made with heavy machinery the vertical pipe may fall over, become damaged, or collapse. Especially for the first layer, the leachate collection discharge pipe directly connected to the gas venting facility may also be damaged; therefore, contact by heavy machinery must be prevented. Furthermore, if landfill is filled higher than independent gas venting facilities, the gas venting facility may become buried. If this happens this gas venting facility can no longer be added to or raised in the next landfill layer. If this is left as it is, air can no longer be supplied, the aerobic area inside the waste layer is reduced and the Fukuoka Method can not be maintained. (See Picture 3-4 ~ 5)

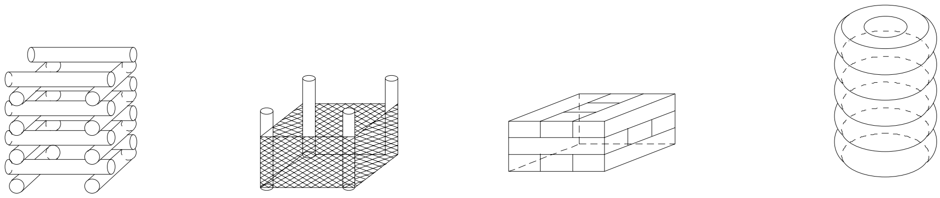
Picture 3-4 Waste is higher than Gas venting facility (○) case (bad example)

Picture 3-5 Gas venting facility that is in the process of being plugged and buried (bad example)

• Preceding Independent type case

In the case of independent preceding type where gas venting facilities are raised to a height higher than the height for the landfill prior to implementing landfill operation and then proceed with landfill (see Fig. 3-6, picture 3-6), care is needed to perform landfill operation not from only one direction but in a uniform manner in the surrounding area to prevent falling down, damage, or breaking.

The independent height is higher than the planned height for waste and care must be taken so that waste or covering soil does not flow into the facilities after landfill operation. In the case that there is a possibility of becoming buried, after landfill around the gas venting facility is complete pile crushed rock beforehand such that the gas venting facilities are at least 50 cm higher than the surrounding waste. (See Fig. 3-8)



Double cross arranged type   Nets fabricated type   Gabion accumulated type   Waste tire accumulated type

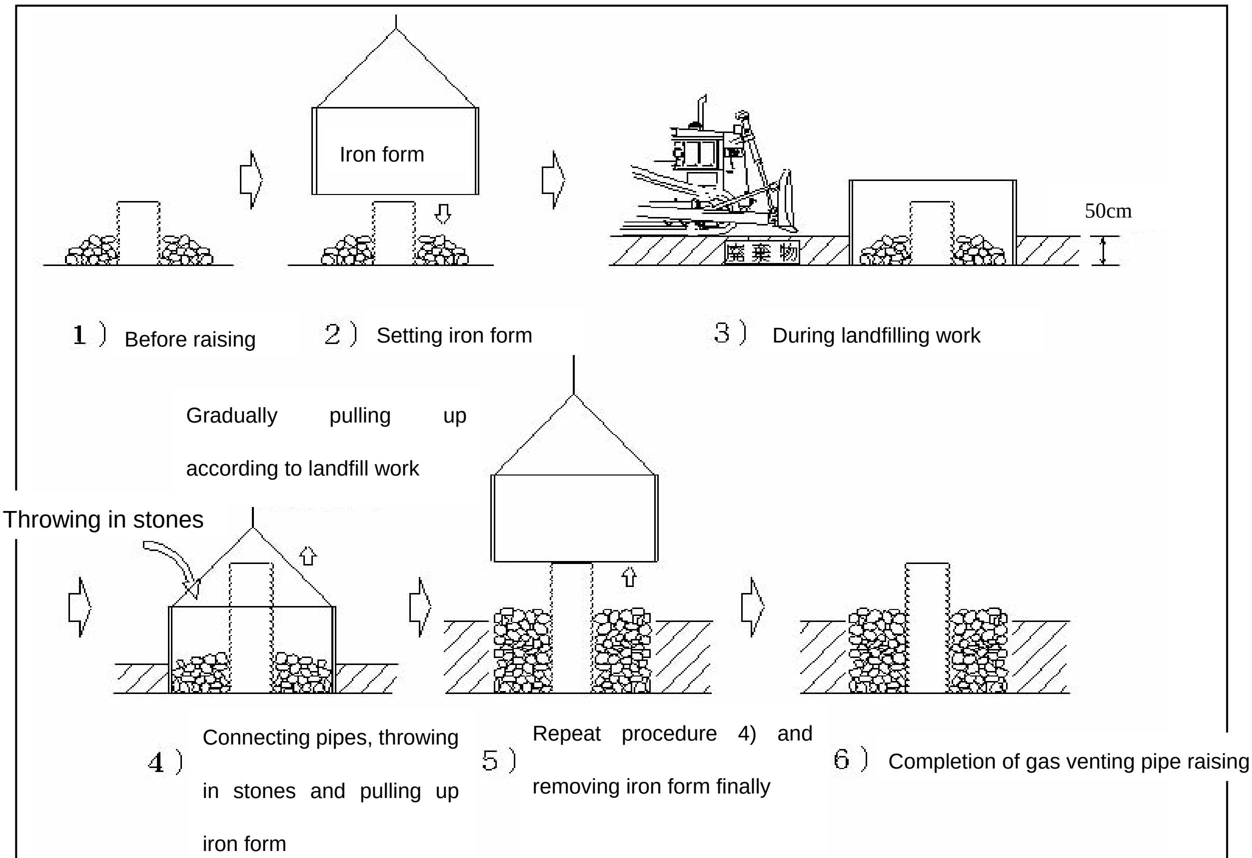
Fig. 3-6 Vertical pipe construction (preceding independent type) construction example

Picture 3-6 Vertical pipe construction (preceding independent type) construction example

・Post construction type

A method of temporarily placing a steel frame of the gas venting facility that is scheduled to be raised and after burying the outer circumference of the steel frame, putting crushed rock in the steel frame and proceeding with raising (see Fig. 3-7) enables prevention of being knocked over, being damaged, or collapsing as well as achieving efficient raising operation.

Picture 3-7, 8 Construction example of raising post construction type gas venting facilities



1) Install the steel frame using heavy machinery such as a backhoe

2) Perform landfill operation around the steel frame (from the perspective of plugging the pipe, waste material that is in rough pieces is suitable)

3) Connect the pipe and put crushed rock in the steel frame

4) Pull up the steel frame using the heavy machinery such as a backhoe

5) Repeat the above operation to raise the structures

Note 1 when a worker is working inside the steel frame, be sure to measure oxygen concentration before and during operation and take countermeasures for lack of oxygen as well as presence of toxic gases

Fig 3-7 Post construction type gas venting facility raising method

3-3 Considerations for maintaining the aerobic area of the landfill waste layer

【Abstract】

For the Fukuoka method, the landfill waste layer must be maintained in an aerobic condition. Therefore, countermeasures regarding layer thickness of the landfill waste layer must be taken during the landfill operation stage. If the layer is thick an air flow pipe and layer of crushed rock need to installed in the middle.

【Explanation】

(1) Requirements

The Fukuoka Method is a technology that maintains the waste layer in an aerobic state to the extent possible, promotes decomposition of waste using aerobic microorganisms, and that improves the quality of both leachate and gas that is generated. Therefore, actions must be implemented during landfill operation to expand the aerobic zone inside the waste layer, to reduce areas that retain leachate, and maintain an aerobic environment to the extent possible.

(2) Support Example

In cases where the landfill layer is less than 20 m and where the land fill layer is more than 20 m with a lot of decomposable organic material, implement the following method as part of the landfill operation.

(i)Use material that readily transfers air as the daily soil covering (for case where landfill layer thickness is less than 20 m)

If a material with a low coefficient of permeability such as clay material is used for the covering soil used for daily covering, air supply is stopped by the covering layer for each layer. In other words, as the leachate generated through waste decomposition may be retained by the covering layer (see Fig. 3-8), use of a soil covering material with a coefficient of permeability that is as large as possible is desirable.

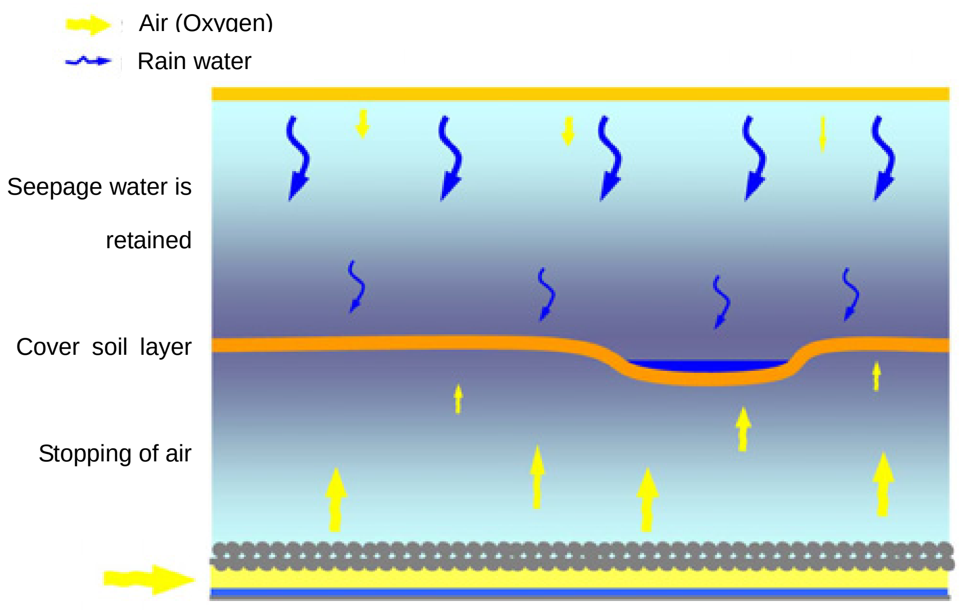


Fig. 3-8 Bad effect due to cover soil with argilliferous soil (Imaginary picture)

As shown in Fig 3-8, if the daily soil covering is implemented with clay like soil, the air (oxygen) that is supplied through the leachate collection discharge pipes is stopped at the soil covering layer. Furthermore, leachate from rain or generated by decomposition of waste may be retained in the waste layer. If this occurs, anaerobic zone expands centered on the soil covering layer and hinders progress of waste decomposition. In order to prevent this, it is desirable to use a soil covering material that transmits air easily and has high permeability (gravel or sandy soil etc.). It follows that while in general the daily soil covering material is selected based on considerations for stable supply and economics, the permeability of the soil covering material must also be considered as selection criteria.

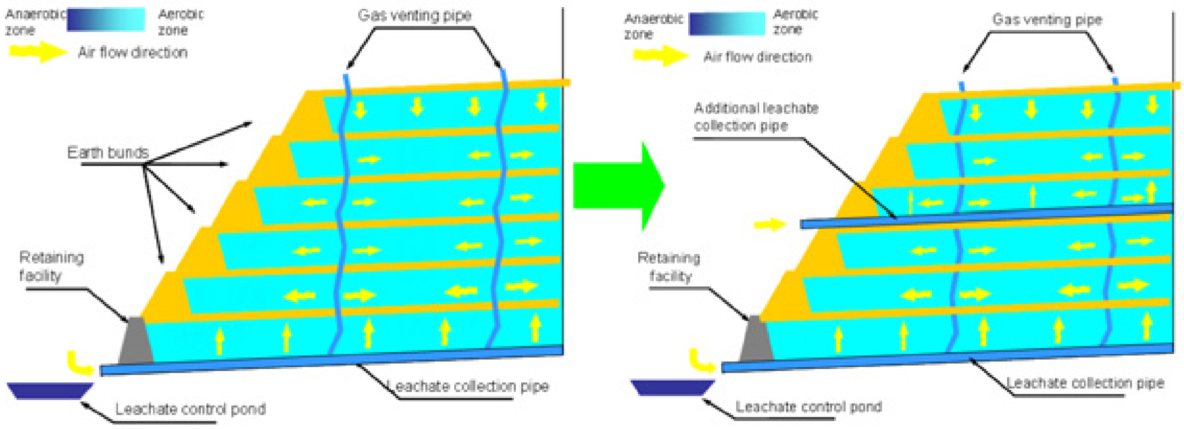
If use of a soil covering material with poor permeability can not be helped, rainwater etc. may be retained on the surface of the soil covering. If the next landfill layer is put on in this state, a barrier layer is generated in the waste layer. In this case, either remove the cover soil just prior to fill of the next layer or make water paths to guide retained water to gas venting facilities to prevent generation of a barrier layer for air and leachate. (See Fig. 3-9)

Picture 3-9 Unlined side ditch for waste water in the site (guide to gas venting structure)

(ii) Install air influx pipe or crushed rock area layer as a center soil covering layer. (Case where landfill layer thickness is more than 20 m)

Supplying of air (oxygen) to the waste layer is the most important element for maintaining the Fukuoka Method and expanding the aerobic area. Supply of air (oxygen) to the waste layer is provided through (1) leachate collection discharge pipes at the bottom (2) gas venting facilities, and (3) soil covering surface. However, it is said that the permeation of air (oxygen), while depending on the type of waste material, is roughly 5 m and as shown in Fig. 3-9 (1), anaerobic areas expand with greater distance from the air supply facilities. Furthermore, there is also the possibility of permeation water and leachate generated through decomposition being retained especially on the surface of the soil covering layer. If a retention layer is developed, an anaerobic area expands and the quality of the leachate may be worsened.

Therefore, especially in mountainous areas where the disposal site will have a height of higher than 20 m, installing of horizontal air (oxygen) supply facilities and leachate removal facilities every roughly 20 m of landfill layer to rapidly remove leachate and expand aerobic areas such as a crushed rock area and/or air flow pipes is desirable. (See Fig. 3-9 (2))



(1) Before installation of central air pipes (2) After installation of central air pipes

Fig. 3-9 Semi-aerobic (aerobic area and anaerobic area) image diagram

(iii) Make a wall of crushed rock directry above the leachate collection discharge pipes up to the final landfill layer

Expanding of aerobic area in the waste layer to the extent possible and removing leachate rapidly promotes decomposition of waste and are effective at improving the quality of the leachate. Therefore, leachate collection discharge pipes are installed and landfill is performed while raising vertical pipes and sloped surface gas venting facility. In order to further maintain the waste layer in an aerobic condition and efficiently collect leachate, in addition to vertical pipes, it is desirable to make a crushed rock wall directly above the leachate collection discharge pipes up through the final layer.

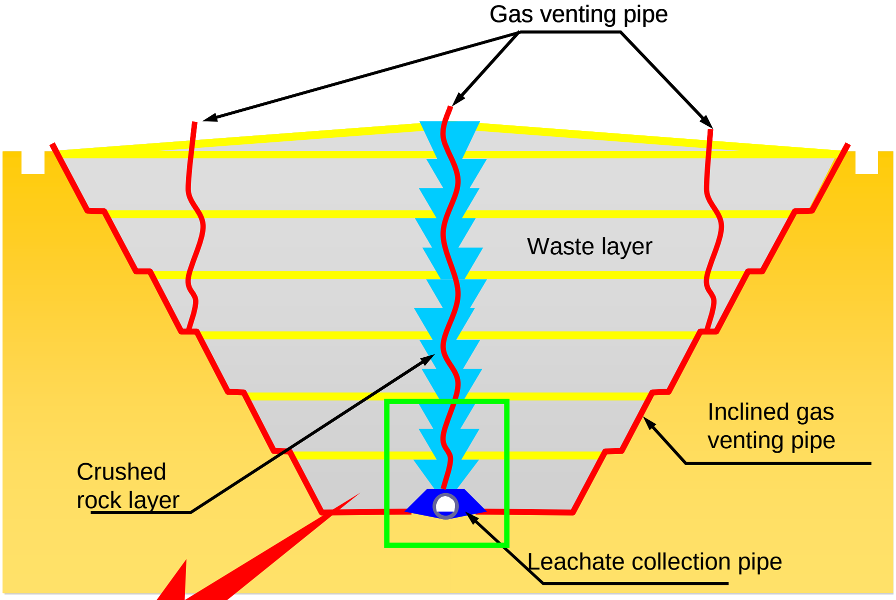
Especially in disposal sites near mountains, the disposal sites are deeper and larger and use of only vertical pipes and gas venting facilities can make it difficult to remove rainwater (leachate) from the disposal site and expand the aerobic area of the waste layer. Furthermore, higher landfill heights generate larger surface area per layer which can easily make collection of rain water and leachate difficult. In this case, it is desirable to make a crushed rock wall directly above the leachate collection discharge pipes, which are on the bottom up through the final layer. This action enables more reliable collection of rainwater and leachate as well as air supply through the leachate collection discharge pipes. Fig. 3-10 ~ 12 show an example used by Asahikawa-shi in Japan.

The essentials of construction are according to the following.

a) Terminate landfill continuously with a width of at least 1 m directly above the leachate collection discharge pipes.

b) Fill the area not filled in with crushed rock.

c) Implement the operations of i) and ii) through the final layer.



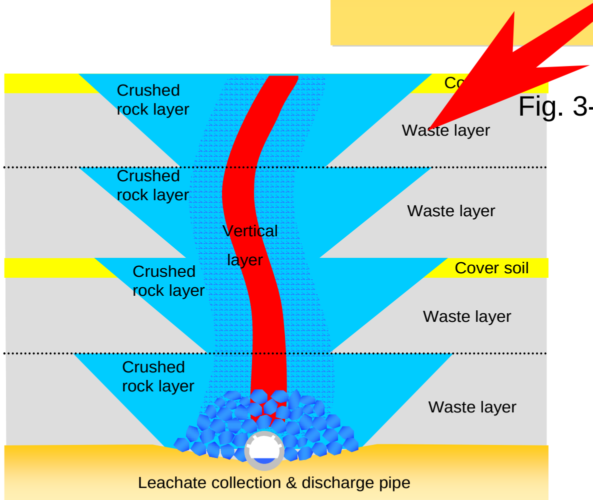


Fig. 3-10 Cross sectional diagram of crushed rock layer

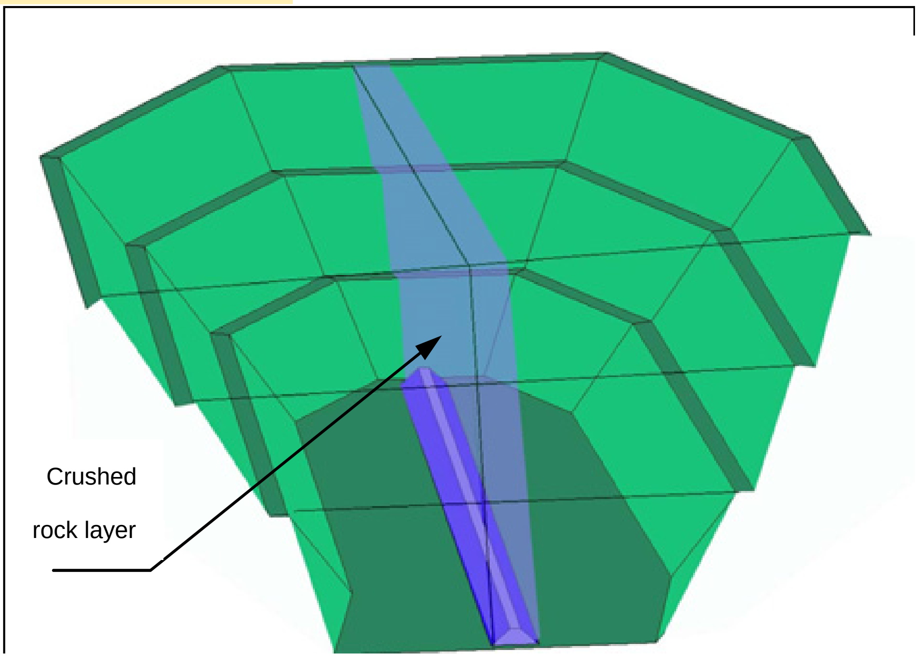


Fig.3-12 Completion Diagram of Crushed rock vertical layer (Imaginary picture)

3-4 Other・Consideration for recirculation of leachate

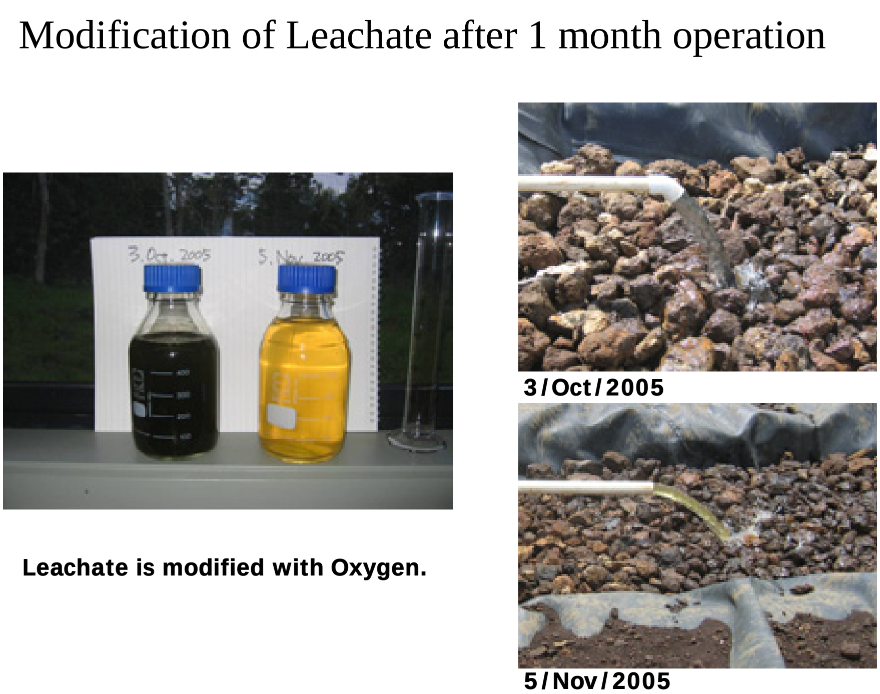
【Abstract】

It is desirable to saturate the waste layer with leachate in order to fully utilize the water retention, evapo-transpiration effect, and purification functions of the waste landfill layer to its utmost potential. Therefore, the final layer of the area that will be saturated with leachate should not be compacted more than necessary, should be filled with rough waste, and consideration is needed such as covering with soil after completing circulation etc. Furthermore, the saturation area can be made higher than the surrounding area to prevent rainwater from flowing into the saturation area.

【Explanation】

(1) Requirements

Leachate that is collected by the leachate collection discharge pipes is temporarily retained in a control pond and by re-circulating the leachate through the waste layer of the disposal site, the leachate quality can be improved using the (1) purification effects of the waste layer itself. (See picture 3-10) Therefore, it is necessary to assume that recirculation from the leachate control pond to the waste layer of the disposal site will be performed.



Picture 3-10 Seepage water purified through recirculation

In addition to improving quality of water, recirculation of leachate is also effective at reducing the load in case the treatment facility is small scale or imperfect as well as an effective technology for controlling the water level of the leachate control pond at times when leachate treatment can not keep up such as when a lot of rain falls in a short period of time such as during the rainy season.

Therefore, in order to smoothly re-circulate from the leachate control pond to the landfill site, it is desirable to consider the location and landfill height and prepare piping and facilities. (See Fig. 3-13)

(2) Application Example

Picture 3-11 Shows and example of circulation through laying of crushed rock in the bottom of the circulation pit and drawing up leachate using a pump

Measures for preventing flowing in of rain water

① Construct dikes surrounding the recirculation pit

② Adjust the gradient of landfill

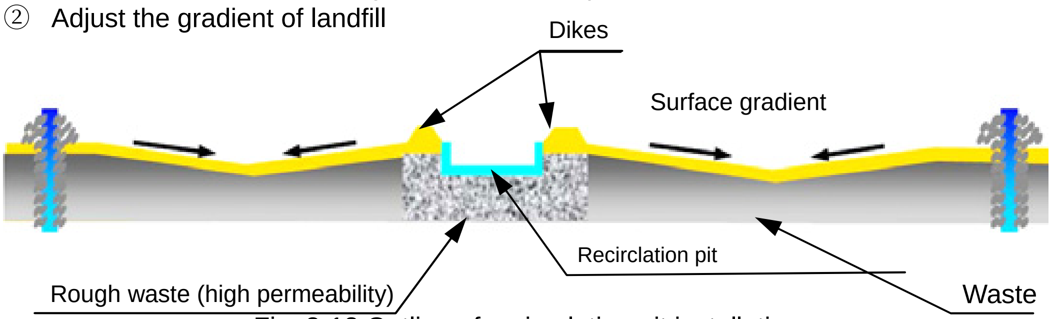


Fig. 3-13 Outline of recirculation pit installation

Picture 3-11 Example of landfill site in Tafaigata, Samoa (circulation pit)

4. Environmental Monitoring

4.1 Understanding Aerobic and Anaerobic Conditions

【Abstract】

Creating aerobic areas in the wastes layer enhances decomposition of the wastes and improves the quality of leachate and gases so that reduces the environmental risk and global warming. The “Fukuoka Method” is a landfill system that expands the aerobic area in a waste layer. To evaluate if the “Fukuoka Method” has been designed and is being controlled correctly, it is necessary to monitor whether or not aerobic areas have developed in the wastes layer. Monitoring items include CH_4, CO_2, and H_2S concentrations in gases generated from landfill, pH, and BOD concentration, ammonium and nitrate concentrations, and soluble iron and soluble manganese concentrations in leachate.

【Explanation】

(1) Remarks

Decomposition of wastes (organic substances) is divided broadly into two processes of solubilization and gasification. In the solubilization process, soluble organic acids, ammonia, and CO2 etc. are produced, resulting the increase in the BOD load of leachate and the decrease in pH. In the gasification process, as gas is produced from the organic acids, etc. BOD load is reduced and pH increases. These two processes are influenced by the biological conditions of the wastes layer. In an aerobic condition, organic substances are decomposed by aerobic microorganisms; the time span of the first stage solubilization process (hydrolysis of organic substances) is short and transition to the second stage gasification process is rapid. In other words, as aerobic decomposition progresses, BOD load is reduced early on and pH increases. Therefore, monitoring BOD and pH enables understanding of the degree the wastes layer is aerobic.

Also, the final products generated through aerobic decomposition in the gasification process are oxides such as CO_2, nitrate and sulfate ions. On the other hands, in the case of anaerobic decomposition, the final products are reducing substances such as CH_4, H_2S, and ammonia. The products by the decomposition of organic wastes are different based on the biological conditions of wastes layer. The existence of aerobic area in wastes layer can be determined through measuring the quality and quantity of the gases generated from landfill and calculating these gases ratios. As these two processes are separated into 6 phases from the differences in concentration of pollutants and the generation volume of and composition of gas (see Fig. 4-1, decomposition pattern), this can also be used as an indicator of landfill stabilization.

Furthermore, in the cases that metals are included in the wastes, iron and manganese are reduced in anaerobic conditions and as this makes them more soluble, the concentration of iron and manganese in the leachate increases. Therefore, the degree that the wastes layer is anaerobic can be determined through measuring the concentration of soluble iron and manganese in the leachate.

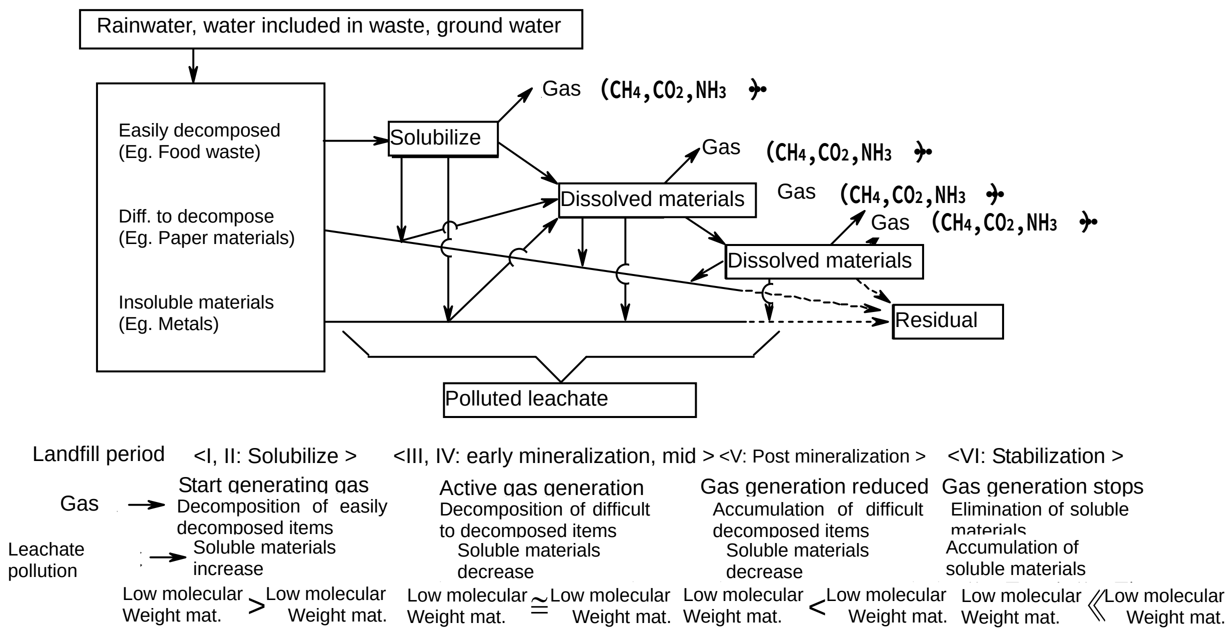


Fig. 4-1 Landfill waste material decomposition patterns

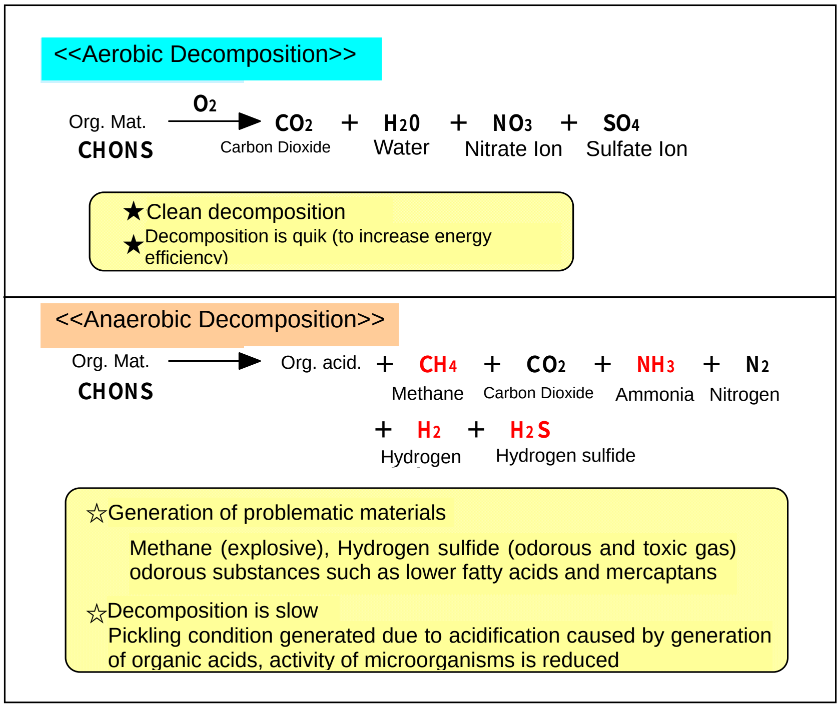


Fig. 4-2 Outline of Aerobic and Anaerobic Decomposition

(2) Measurement example

(i) pH and BOD concentration of leachate

a. pH measurement method and note for a measurement

pH test paper is best suited for measurement of pH on site. There are various types of pH test paper but a universal type of pH test paper is sufficient to gain a rough level of pH such acidic, neutral and alkali. Even if sample contains a lot of suspended matter, or if is colored, the pH can be measured within a error of roughly 0.2 to 0.4. Name of pH test papers and their applicable pH levels are shown in table 4-1.

If the pH test paper is left in leachate for a long period, the chemicals containing the test paper will dissolve into leachate and will be removed from test paper. If the test paper is touched by hand, it will change color due to sweat etc. so use tweezers or something similar for dipping in leachate. If tweezers are not available, pick up the edge of test paper and be careful not to immerse a part of paper that you are touching.

Use pH test paper with specified measuring range or a pH meter for accurate measurement of pH. There is various type of pH meter with the different accuracy but devices for accurate measurement are not required. As the electrodes of pH meter are made with a thin glass film they are easy to break so be careful when using them. Store with the electrodes immersed in water.

Table 4-1 pH test paper names and applicable pH levels

CR	Cresol Red	0.2 – 2.0
		7.2 – 8.8
tb	Thymol Blue	1.4 – 3.0
		8.0 – 9.6
BPB	Bromophenol Blue	2.8 – 4.4
PB	Phenol Blue	3.2 – 5.6
BCG	Bromocresol Green	4.0 – 5.6
CPR	Chorphenol Red	5.0 – 6.6
MR	Methyl Red	5.4 – 7.0
BCP	Bromcresol Purple	5.6 – 7.2
BTB	Bromothymol Blue	6.2 – 7.8
PR	Phenol Red	0.0 – 1.6
		6.6 – 8.2
AZY	Alizarin Yellow	10.0 – 12.0
ALB	Alkali Blue	11.0 – 13.6

b. BOD measurement method and note for a measurement

The BOD is expressed by the amount of dissolved oxygen in sample that is consumed over a 5 day period at 20 °C. In Japan, the Winkler Azide modified method based on manganese oxidation by dissolved oxygen is used as a standard test method to measure the amount of dissolved oxygen. Also, the miller modified method that is based on the oxidation of iron by dissolved oxygen is used as a simple measurement method. In addition, there is a membrane electrode method that generates a current between metal electrodes based on the amount of dissolved oxygen and uses this value to determine the amount of dissolved oxygen. The Winkler Azide modified method and Miller modified method are easily affected by reducing materials such as soluble iron and manganese etc. On the other hand, the membrane electrode method is not affected by reducing materials and measurement is easy but stabilization of the measurement value is difficult.

An important point for a measurement using the above 3 methods is that BOD components decompose and reduce while being stored so the test should be performed immediately after collecting the sample. In addition, as the test takes 5 days, if measurement does not go well, it is difficult to redo the measurement. Therefore, dilution ratio must be estimated accurately. These estimates are preformed based on past results and COD value, color, and smell of the sample. Cases where are 1/2, 1/4, 1/8, and 2, 4, 8 times of the base estimated BOD concentration must also be tested at the same time. Make sure that air can not get into the incubation bottles the incubation period (5 days).

c. Measurement example

The first period of solubilization phase (phase I) is a period where organic material hydrolyzes and where soluble pollutants such as organic acids are produced. Therefore, the BOD concentration is high and pH is acidic ranging 4 – 6 during this period. During the latter period of solubilization phase (phase II) and gasification phase (phase III), a portion of the solubilized organic substances is converted to gas so the BOD concentration is reduced and pH rise. In this period, CO_2 dissolves into the leachate and causes the pH to rise. A semi-aerobic type is more on CO_2 generation than an anaerobic type so that pH of Semi-aerobic type reach to as high as 8. During the middle to latter period of gasification phase (phase IV), gasification is the highest in both semi-aerobic and anaerobic type and therefore, the BOD concentration reduces further but the pH maintains a roughly neutral level. The most of decomposable organic substances is decomposed by the solubilization and gasification processes. Therefore, soluble organic subsutances vanishes and the BOD concentration is a low concentration of less then 10 mg/L in the stabilization phase (phase V). In addition, the alkalinity increases and a pH reach to 7 – 8 due to CO_2 produced in gasification phase.

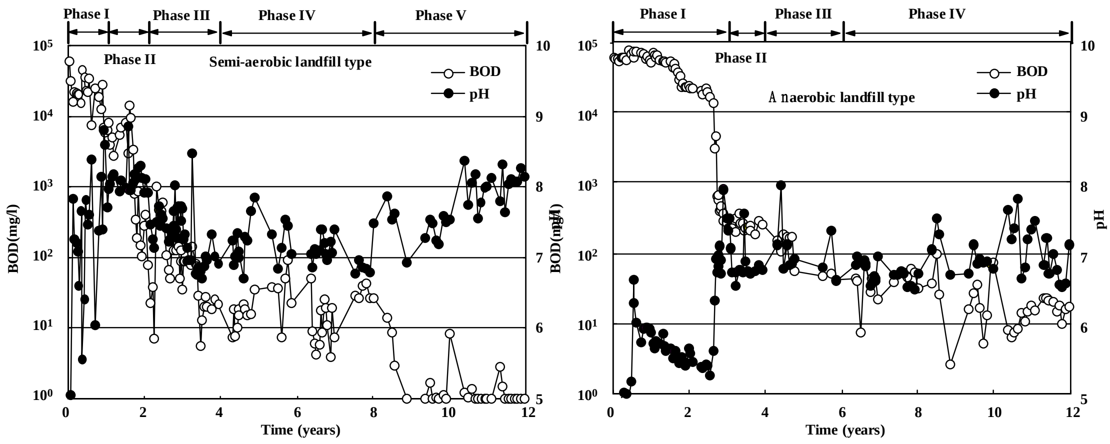


Fig.4-3 pH and BOD concentration variation with time

(ii) Ammonia and nitrate concentrations in leachate

a. Important points for measuring

Nitrogen compounds also biodegrade for storing and change to various type of nitrogen compounds such as ammonia and nitrate etc.. Therefore, measurement should be quickly performed after collecting sample.

b. Measurement example

Ammonia is produced through hydrolysis of organic material. Then, ammonia oxidizes under aerobic conditions and is converted to nitrite and nitrate. As nitrogen oxides are soluble, they dissolve in the leachate. On the other hand, as ammonia does not oxidize in an anaerobic condition and does not change. Ammonia is also soluble and dissolves in the leachate as well. In other words, detection of nitrogen oxides in leachate shows that wastes layer is an aerobic.

In the gasification process where pH increases, part of the ammonia is released as a gas. Therefore ammonia concentration gradually reduces during the gasification process.

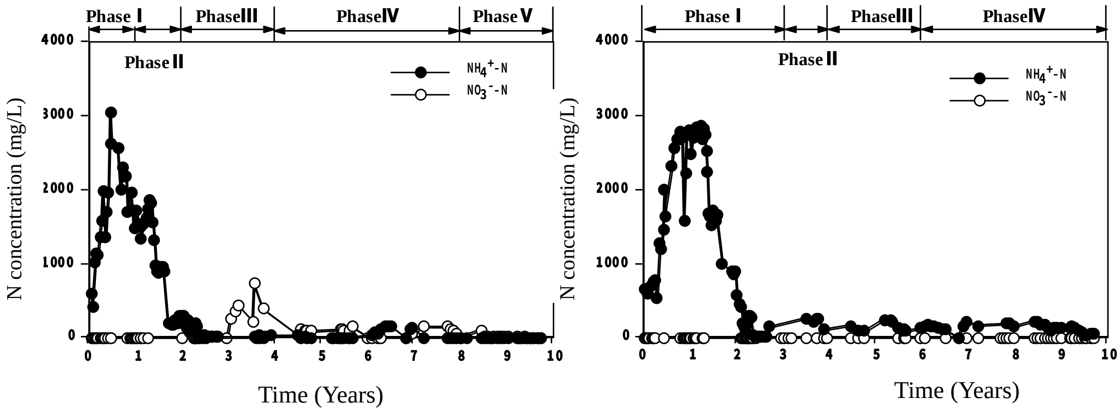


Fig.4-4 NH_4^+-N and NO_3^-N concentration variation with time

(iii) Soluble iron and soluble manganese concentrations in leachate

a. Important points for measuring

Soluble iron and soluble manganese are oxidized by air and become insoluble (precipitates). Therefore, after collecting a sample, quickly filter it and immediately perform acid treatment as pre-treatment for measurement or if this can not be done, add hydrochloric acid and adjust the pH to less than 1 for storage.

b. Measurement example

Heavy metals change from insoluble to soluble based on pH or oxidation/reduction potential. In general, most heavy metals are soluble with acidity. Heavy metals that change based on oxidation/reduction potential are arsenic, iron, and manganese etc. Especially, there is a relatively high amount of iron and manganese in wastes and they dissolve when the oxidation/reduction potential is low, or under anaerobic conditions, and concentrations of these metals increase in the leachate.

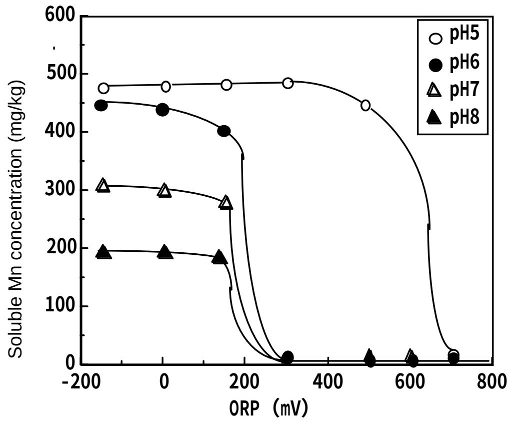


Fig. 4-5 pH ORP affect on solubility of Mn in soil

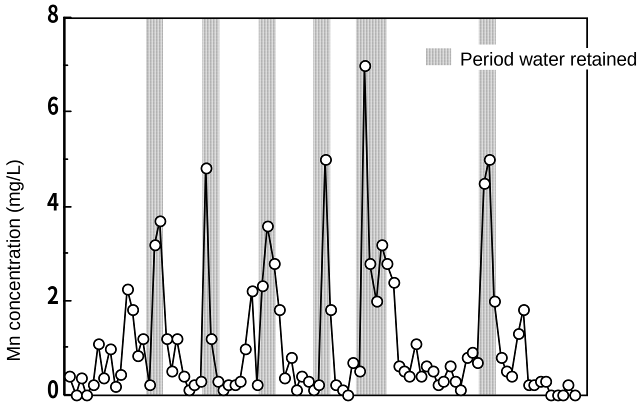


Fig. 4-6 Increase in Mn concentration based on water retention in landfill layer

(iv) $CH_4$and CO_2 concentrations in product gas

a. Measurement method and important points for measuring

Measuring methods for the composition of the landfill gas divided into two types broadly. One method is to analysis using gas chromatography in a lab. Another method is direct measurement at the landfill site. The first method enables analysis of several gas constituents at the same time and has high accuracy but equipment is expensive. Using the second method, one device can only measure one or two types of gas but it is inexpensive and does not require special measurement skills and can be applied to the measurement of CH_4 and CO_2 etc. with accuracy on the order of several %. A flammable gas detection device is used to measure CH_4 and an infrared absorption type or gas detection tube methods are used to detect CO_2. Flammable gas detection devices are developed with the purpose of preventing accidents caused by gas. There are LEL types and the actual concentration measurement type of flammable gas detection devices. The type that measures actual concentration needs to be selected for purchase as well as for measuring. Because the maximum detection range of LEL type is the explosion limit.

b. Measurement example

The gasification process has two path which is aerobic and anaerobic paths. Semi-aerobic type has both aerobic areas and anaerobic areas in the wastes layer. Therefore, the composition of the landfill gas will change based on the ratio of these two areas. As the aerobic area increases, the anaerobic gasification phase (phase IV) shortens and CH_4/CO_2 ratio of phase V and phase VI is reduced. The CH_4/CO_2 ratio based on landfill conditions is shown below.

Aerobic: CH_4 concentration is 0

Semi-aerobic (V, VI periods): $CH_4/CO_2 < 2$

Anaerobic (IV period): $CH_4/CO_2 > 2$

＊ Theoretically $CH_4/CO_2 = 1$ but CO_2 reacts with positive ions in the waste material where it is fixed and dissolves into leachate or precipitate and therefore its concentration in gas is reduced.

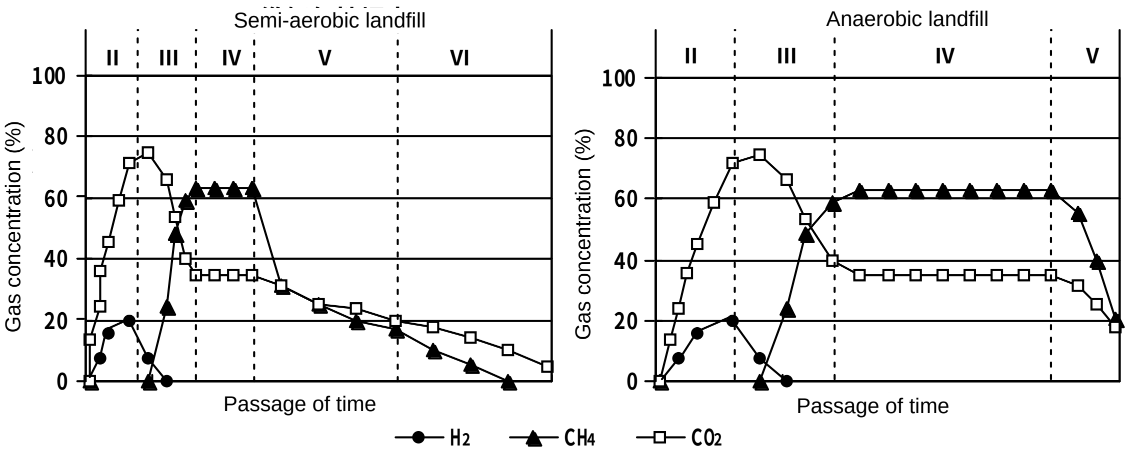


Fig. 4-7 Landfill product gas composition changes

(v)H_2S concentration in landfill gas

a. Measurement method and important points for measuring

Gas chromatography analysis can be used for hydrogen sulfide (H_2S) and for methyl mercaptans (CH_3SH), which are odorous constituents, similar to CH_4 and CO_2 but a induced type gas detection device is easy and inexpensive for measuring of these gases. Also, using this device a prescribed amount (maximum intake amount 100 mL for each time) of gas can be induced into the tip, the amount of intake can be reduced for gas with high concentrations and on the other hand, the number of intake can be increased if the concentration is low. The value noted on the tip is result from one intake so when the volume or number of intakes is changed, some type of calculation such as the dividing the value by the number of intakes is required and therefore care must be taken. There are several types of tips that are classified based on concentration and therefore one with an appropriate concentration range must be selected.

b. Measurement example

When organic sulfur compounds in the wastes are aerobically decomposed by microorganisms, they are converted to intermediate products and in the end to sulfuric acid. On the other hand, when anaerobic decomposition occurs, it changes to odorous substances such as hydrogen sulfide (H_2S) and methyl mercaptan (CH_3SH). Of the inorganic sulfur components, sulfur is converted to sulfuric acid by sulfur oxidation bacteria under the aerobic condition. Therefore, if there are sulfur compounds such as CH_3SH or H_2S detected during the initial (solubilization) phase of decomposition of organic substances, it shows that the wastes layer is under the anaerobic condition.

An anaerobic landfill, there has an aerobic area in the surface layer of the landfill. Therefore, a portion of inorganic sulfur in this aerobic area of the surface layer is converted to sulfate and dissolve into leachate. Then sulfate in leachate is changed again to H_2S by sulfate reducing bacteria in the anaerobic area of the middle wastes layer. Therefore, in an anaerobic landfill, H_2S is not only generated in the beginning of landfilling but there are also cases where high concentrations are detected from 4 to 5 years after starting of landfill operation. In the semi-aerobic type, as there are aerobic areas in the bottom and around the gas venting pipes, H_2S that is produced in anaerobic areas is again oxidized to sulfate. Therefore the H_2S concentration in the gas is reduced. On the other hand, as the sulfate produced by oxidation of inorganic sulfur is soluble, it is discharged with the leachate. In other words, as the aerobic area increases, in addition to H2S concentration in gas being reduced, the sulfuric acid ion concentration in the leachate increases.

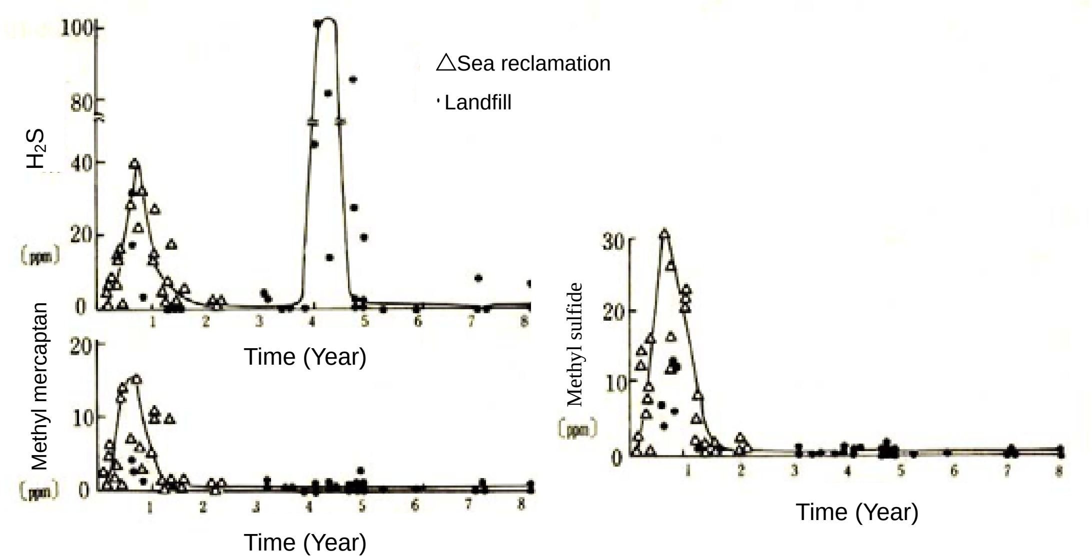


Fig. 4-8 Sulfur compound generation conditions

4.2 Considerations for Stabilization Conditions of Final Disposal Site

【Abstract】

An advantage of semi-aerobic landfill is acceleration of stabilization of landfilled waste by aerobic degradation. Stabilization means that even if the waste materials are discharged to the environment they do not have any impact to the environment. Apart from the heavy metals that do not degraded and disappearance, substances that have an effect on the environment are organic materials that can be decomposed. Degradable organic materials produce pollutants and toxic gases in the degradation process. In other words, stabilization can be evaluated through investigation of organic materials degradation. And also, those materials produce heat of fermentation during the degradation process. This heat accumulates in the landfill site can make the high temperature in the landfill site around 50 °C to 70 °C. If the temperature of the landfill site reduces to outside air temperature, it can be estimated that the heat of degradation and reaction are reduced under biodegradation of organic materials, that easily degradable waste is decomposed and that the landfill site has begun to stabilize.

There is a method of measuring the degraded organic matter with sampled waste material directly. However, a method that analyzing the temperature of leachate, BOD/COD ratio, and amount of gas production is generally applied for evaluation. There is a method to analyze the inside temperature of landfill to measure the temperature of waste layer or leachate just after being discharged from the landfill site.

【Explanation】

(1) Remarks

The target of a semi-aerobic landfill is the degradation of organic material by the micro bacteria that exist in the waste layer. Therefore, the effect of stabilization provided by semi-aerobic landfill can be evaluated by reduction in the amount of organic material. If there is any organic material, a portion of the energy generated by microorganisms is converted to thermal energy and biodegradation products dissolved pollutants and biogas. BOD of the dissolved pollutants indicates the amount of organic matter that is easily biodegradable, so the rate of BOD in the total amounts of organic material (COD) is reduced. The biodegradation is slowness when the amount of organic material is reduced, therefore there is a smaller amount of energy is generated, the temperature of waste layer is decreased, and also the amount of gas production is reduced. The leachate passes through most of the waste layer, so it can be considered that characteristics of the leachate reflects the inside of landfill, but the landfill gas can be measured only at a specific area such as the gas ventilation pipe, so it can not be expected to reflect the whole landfill area. It is possible to measure the amount of gas production on the part of final cover soil but a lot of effort is required to measure the whole surface of a large landfill area. A simple method for measuring amount of gas generated particularly methane gas is the investigation of vegetation on the soil cover. There are some types of vegetation that can be inhibited by gases such as methane. In other words, to observe the growth of these vegetations can be realized the reduction of methane production.

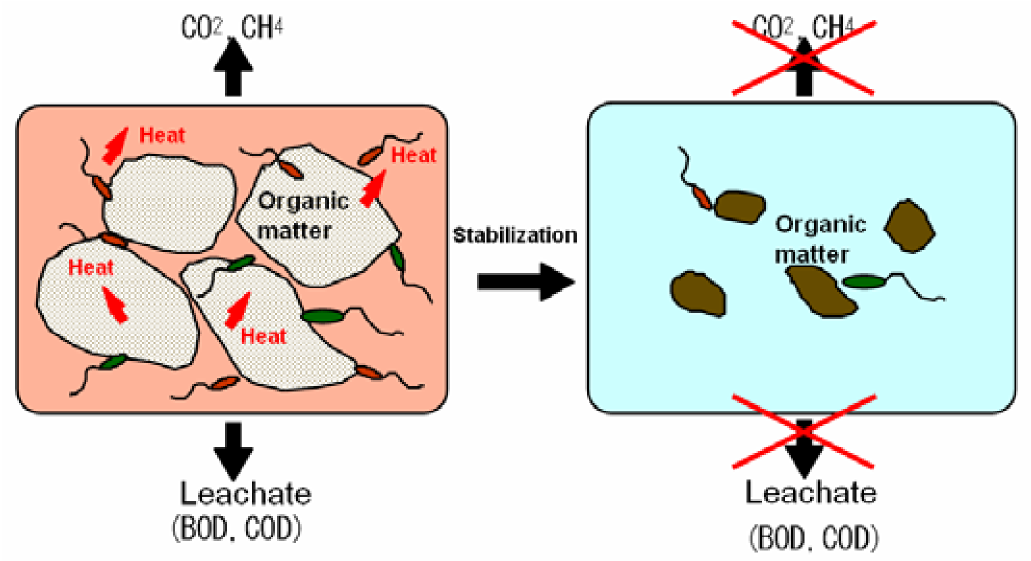


Fig. 4-9 conceptual scheme for stabilization of landfill

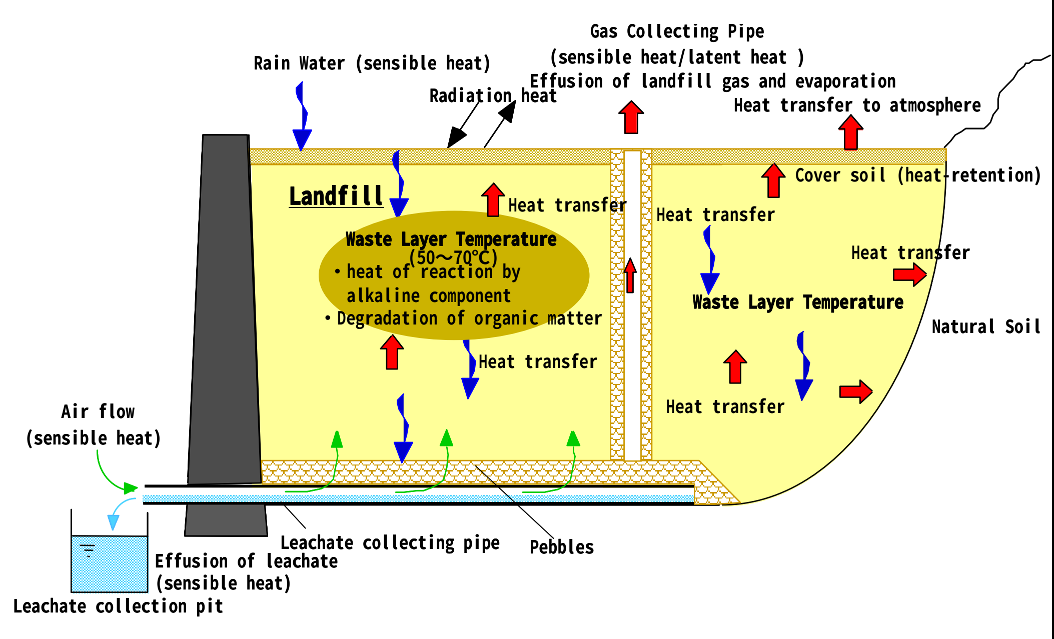


Fig. 4-10 Heat balance in landfill

(2) Measurement example

(i) Temperature of leachate measurement

a. Advantage and simplicity method of leachate temperature

There is a heat balance in landfill to receive inside and release to outside. (see Fig. 4-10). In this figure, the way to recognize the state of waste degradation based on the temperature: (1) temperature from gas collecting pipes (2) leachate temperature from collecting pipe, and (3) temperature of waste layer, throw (2) is easy and low cost. The temperature of the leachate reflects the condition of inside the landfill because rain water passes through the waste layer and heat transfers to the leachate through heat exchange from the waste in the landfill and with the gases. Furthermore, the diagnosis with leachate temperature can estimate by the energy transfer with leachate and rain water temperature and amount of leachate.

b. Measurement method and note for a measurement

> Leachate temperature:

Temperature measurement of leachate using a thermometer and recorder must be measured at the outlet port of leachate collecting pipe or the collection pit. And the sampling water must be analyzed by thermometer just after taking, and the temperature of rain water is measured periodically by a thermometer.

>Leachate amount:

The leachate volume must be measured from collecting pit every day.

c. Measurement example

Biodegradation Diagnosis using water temperature is performed from (1) temporal change of leachate temperature and amount and (2) amount of thermal energy discharged by leachate calculated from the following equation.

Amount of thermal energy transfer to leachate:

$$Q = V_L\ ({}_TL - T_W)\ C_P\ [J]$$

T_L: temperature of leachate [°C]; T_W: temperature of rainwater [°C]; V_L: volume of leachate [L]; C_P: specific heat of water = 4.18 [KJ/kg-K]

Temporal change of the leachate temperature and the accumulation of amount of energy discharged based on the equation in every month show in Fig. 4-11.

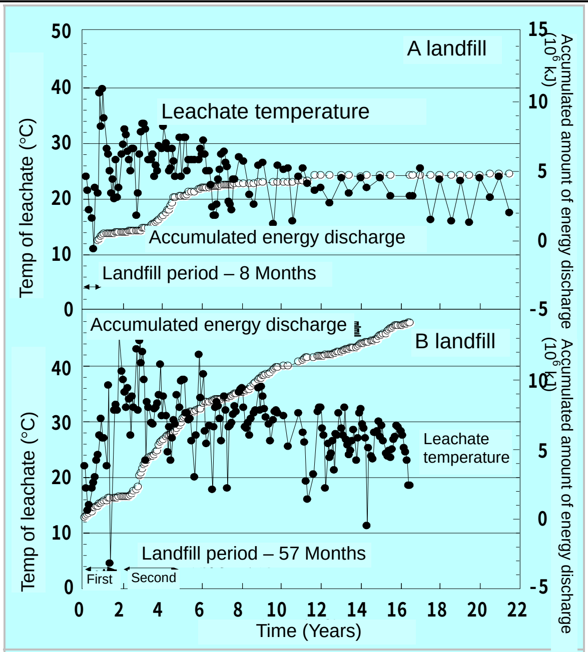


Fig. 4-11 Temporal change of leachate temperature and accumulated energy discharge amount

From this figure, both of landfills A and B show a leachate temperature of 30 ~ 40 °C in the primary period, but after 15 years A landfill showed around 20 °C, the same temperature as ground water, means getting a stabilizing. It can be judged that it will take a little longer for B landfill to stabilize around 25 °C.

Change in temperature of leachate is easily affected by surroundings temperature such as the summer and winter as well as rain water, so there is a difficult case to judge it. From the results of the amount of thermal energy for each month in landfill A, is shown that the accumulation of energy discharged in the leachate in every month is low and it can be estimated that there is not any heat generation inside the landfill. The degradation of the waste is almost complete and the landfill can be judged to be stabilizing.

On the other hand, there is a lot of thermal energy generated in the B landfill and the accumulated amount of thermal energy shows still increasing. The landfill is generating thermal energy and therefore it can be judged that degradation is currently proceeding and that the landfill has not entered the stable period.

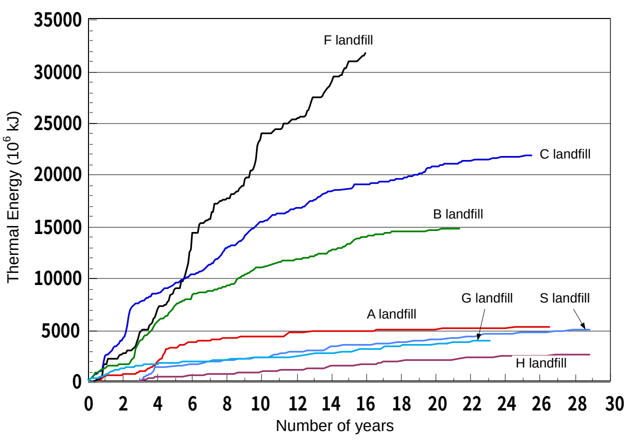


Fig. 4-12 Accumulated thermal energy discharged through seepage water

Examples of accumulated thermal energy amount discharged through leachate of several landfill sites are shown in Fig. 4-12. Based on Fig. 4-12, the amount of increase in accumulated energy discharged by leachate from the landfill sites A, G, H, and S. This result show that the waste in these landfill sites has been decomposed and reaches in a stable condition.

On the other hand, F landfill is in running so accumulated energy discharged to leachate still increases with time showing that decomposition of waste is activity in the landfill site. Landfill operation for B and C landfills is completed and as the increase in amount of accumulated thermal energy discharged is gradually going down, it shows a trend of stabilization of waste.

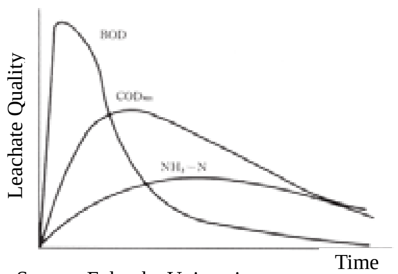
(ii) BOD/COD of leachate

a. Measurement method and note for a measurement

Following 1) of chapter 4-1.

b. Measurement example

The quality and concentration of leachate is depending on the type of landfilled waste. In generally, the trend of landfill which filled mainly with organic material is shown the water quality pattern as Fig. 4-13, and they show a trend of BOD > COD. In addition, as nitrogen components in waste material gradually degradable, so TN in leachate shows increasing after long period. However, in a landfill site filled mainly with organic material, if the landfill is maintained with an aerobic condition, BOD is rapidly decomposed by microorganisms (see Fig. 4-14).



Source: Fukuoka University

Fig. 4-13 General trends of leachate quality

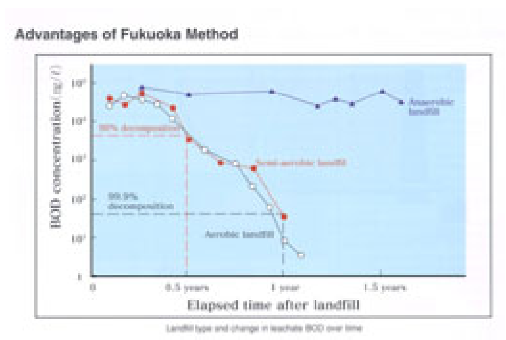


Fig. 4-14 BOD of leachate from landfills mainly filled with organic material

The leachate quality of a semi-aerobic landfill of incombustible waste and incineration residue is shown in Fig. 4-15. In a landfill site that sufficiently maintains the function of a semi-aerobic construction, the BOD (easily biodegradable organic matter) degrades in early stage and the COD (hardly biodegradable organic matter) decrease gradually, so it has a trend of BOD < COD. In addition, TN in leachate shows increasing due to nitrogen components in waste gradually degraded and dissolved into leachate after several years from the starting operation.

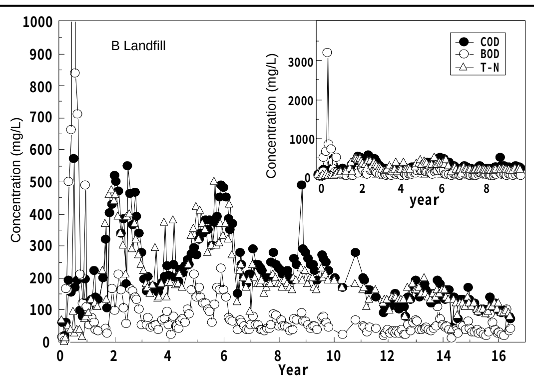


Fig. 4-15 Leachate quality of landfill by mainly incombastible waste with semi aerobic construction

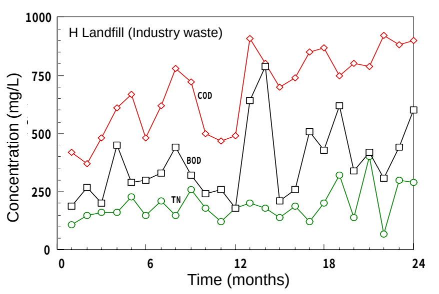


Fig. 4-16 Leachate quality from a landfill of industrial waste

This Fig 4-16 is an example of leachate quality from a landfill site of industrial waste. The H landfill site had a relationship of BOD < COD from just after startup of the landfill and it is the prior stage of TN discharge.

The quality of leachate discharged from the landfill is greatly influenced by differences in the landfilled waste and also differences in aerobic/anaerobic environment of the landfill. However, if leachate is remained underwater (anaerobic condition) in the landfill, the quality became pejoration and in the case that leachate is not remained inside (aerobic or semi-aerobic condition) a BOD < COD trend that means the quality will quickly become favorable can observe.

(iii) Amount of gas production (final cover soil)

a. Measurement method and note for a measurement

As a method for measuring the amount of gas production from the final cover soil, a chamber method which set the chamber on the surface and calculating the flux of methane and carbon dioxide concentrations by the temporal change is generally used. In this method, the gas which is inside of the chamber should be sampled without any influence from the gas pressure, therefore a mixing device to maintain a homogeneous in the chamber is necessary. Also, the measurement time limit must be less than the time until each gas concentration reaches to gas saturation period, so the measurement time is less than 20 minutes in general.

In the case to evaluate the methane production by vegetation, these plants must be selected the normal plants that grow on bare land. However, as the vegetation differs with regions, a type of vegetation that is highly sensitive to methane concentration needs to be confirmed in order to research the relationship between gas concentration and vegetation.

b. Measurement example

As mentioned before the amount of gas generated from the final disposal site differs with the landfill construction of the landfill. In an aerobic construction, 70% of the organic material in the landfill site is discharged as landfill gas, but in an anaerobic construction there is less gas generation. This is because in an anaerobic construction, the soluble organic components produced are discharged as leachate during degradation of organic material in the acid fermentation period. Also, the stabilization period which means after completely decomposition of organic material and the period where little or nothing generation of gas is prospected to be roughly 10 years for an aerobic construction. A semi-aerobic construction shows a similar gas generation pattern as aerobic construction but as the speed of generation is lower. Due to the period where gas generation is delayed compared to aerobic construction, it is considered that it will approach stabilization within 20 years. On the other hand, splitting the gas generation curve for an anaerobic construction into two parts at the 5^{th} year, the curve for years 5 ~ 10 is a straight line and there is no decrease in gas generation seen after the 10^{th} year.

Measuring the amount of gas generated from the huge surface area such as the landfill requires a lot of work. Here, an example of evaluation of stabilization based on amount of gas generated using vegetation as a simple method is introduced. In general, methane affects growing of vegetation, but this effect differs greatly based on the type of vegetation. In the case that monitoring the amount of gas generated is necessary to choose some plants with high sensitivity to methane. Growth range of vegetation with respect to methane concentration is shown in Fig. 4-17. In the vegetation that grows naturally, growth of *arrowroot* and *tall golden rod* is hindered by a methane concentration of 0.02%. Growth of these plants is an indicator of reduction in methane concentration. In other words, if these plants are growing in the final cover soil, there is very little generation of methane which means it can be evaluated as being in stabilization stage.

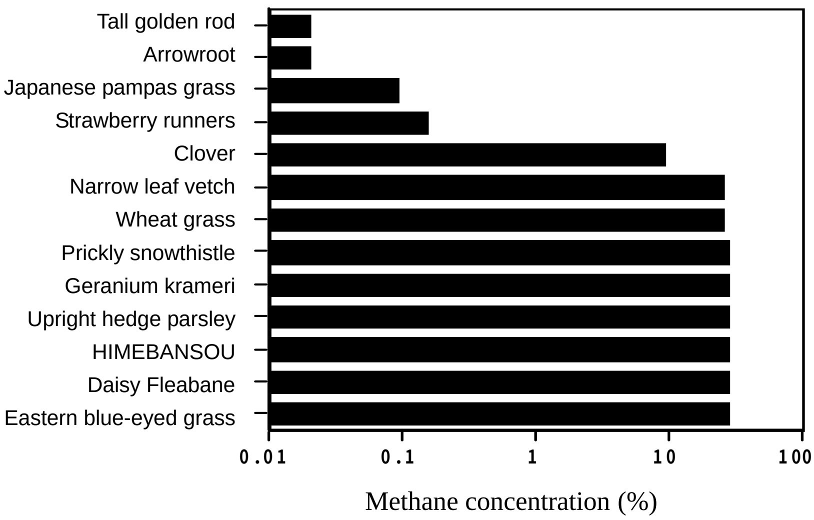


Fig. 4-17 Methane sensitivity of various plants