Chapter 3 Stormwater Drainage Facility

3.1 Functions of Stormwater Drainage Facility

Stormwater drainage facility is installed to reduce the amount of leachate generated from landfill sites. In other words, it functions to prevent stormwater from surrounding areas to enter the landfill sites. Simultaneously, stormwater dropped on the landfill site shall be discharged without any contact with solid wastes.

Following conditions are required for the construction of stormwater drainage facility:

- Drains shall be constructed surrounding the landfill site to prevent the outside stormwater from flowing into the landfill site.
- Dykes or embankments shall be installed if necessary to prevent the stormwater from landfill areas where landfilling activities have not started to flow into the waste layers.
- Drains shall be constructed on the surface of landfill final soil cover at completed landfill areas to separate the stormwater from leachate and drain off the stormwater from the landfill areas.

Rainfalls at a landfill site and its surrounding areas will flow into the landfill area depending on the topography of the area. The rainwater volume is usually much higher than the volume of leachate generated within the landfill site. If this rainwater was seeped into the waste layers, the leachate treatment facility will definitely become not capable to treat the fluctuating and large amount of leachate generated. In order to avoid such situation, it is necessary to separate as much as possible the stormwater from entering the waste layers by constructing a stormwater drainage facility surrounding the landfill area. However, the amount of stormwater on the surrounding area and its volume flowing into the landfill site are depending on the topography and condition of environmental disruption of the area.

3.2 Types of Stormwater Drainage Facility

The stormwater drainage facility can be classified into the following categories:

- Perimeter trench drain
- Trench drain in landfill site
- Landfill surface drain
- Upstream diversion channel

Stormwater drainage facility serves as part of the overall drainage network in the sanitary landfill system to reduce leachate volume generation through removal of rainwater. It can be classified into the following categories as illustrated in **Figure II-5** below. The conceptual illustration of the constituents in a stormwater drainage facility is shown in **Figure II-6** below.

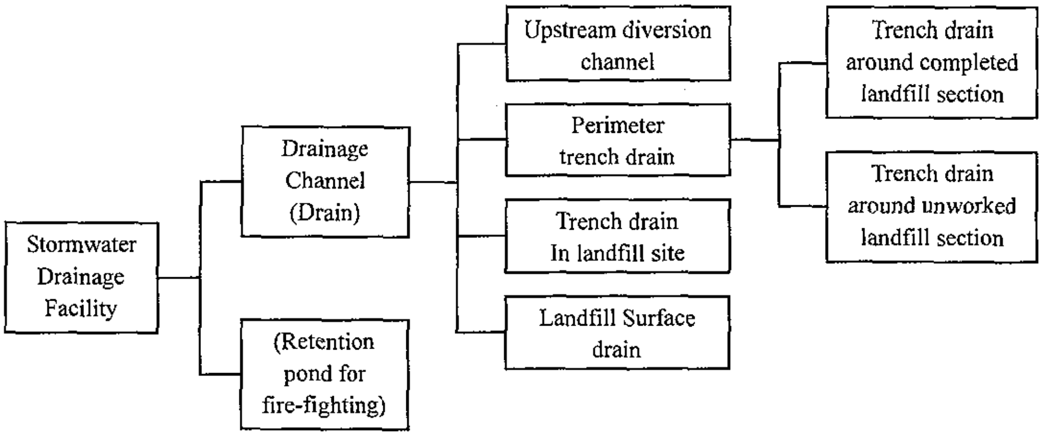


Figure II-5 Classification of Stormwater Drainage Facility

(1) Perimeter Trench Drain

The perimeter trench drain is usually constructed surrounding the landfill site before the commencement of landfilling operation. It collects rainwater from the surrounding area and functions to prevent the stormwater from seeping into the waste layers. The catchments area for designing the total stormwater discharged volume shall be taken into consideration so that the drain would be able to handle stormwater from the surface of the final cover upon the landfill completion.

The longitudinal gradient of the perimeter drains are depending on the topographical conditions. Generally, 1 to 2% slope is adopted. It is important to take into consideration the erosion and hydraulic jump during the design process, which is caused by swift flow and sharp curves occur frequently at steep or undulating ground.

The commonly used perimeter drain structures are in-situ concrete-bed channel, U-ditch, corrugated flume etc.

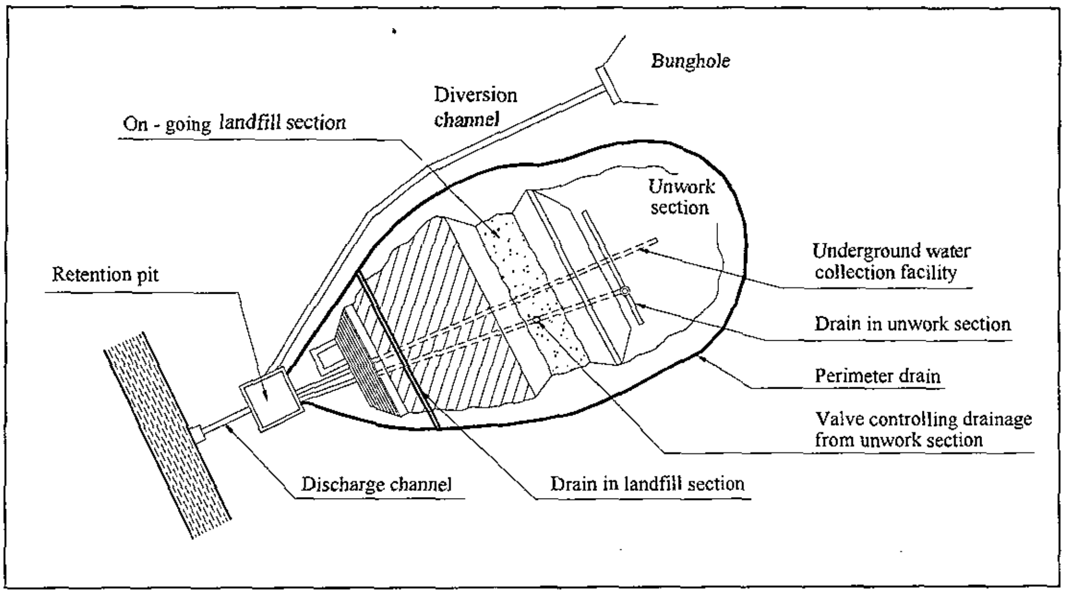


Figure II-6 Concepts of Stormwater Drainage Facility

(2) Trench Drain in Landfill Site

Trench drains built in the landfill site function to expel rainwater from the landfill site before it reaches the landfilled waste layers. It can be further categorized into trench drains around completed landfill section and trench drains around un-worked landfill section.

The trench drains around completed landfill section is installed on the landfill site after the application of final cover soil in order to drain off the stormwater. On the other hand, the trench drains around un-worked landfill section are functioning to drain off the rainwater in the un-worked landfill section in order to avoid it from mixing with the wastes. The construction of this type of drain is desirable if section landfilling is undertaken. Sometimes the collected rainwater is discharged through the underground water drainage facility. However, if these drains were not carefully closed after the commencement of landfilling for this section, there will be possibility of leachate flow into the underground water drainage facility, which may create serious environmental pollution or disaster. Such planning and design concepts shall be avoided.

The common types of trench drains built in the landfill site are Hume pipes, synthetic polymer pipes, corrugated pipes etc.

(3) Landfill Surface Drain

Landfill surface drains are installed to drain off the surface stormwater after application of the final cover soil. Surface drains are dug to the required slope (commonly 1 to 2%) on the fully compacted final cover layer.

The rate of ground subsidence is high at the early stage of landfill completion. Therefore, it is better to adopt simple type surface drains such as an open ditch land with sheet liner in the beginning. When ground subsidence has settled down, concrete based ditch shall be constructed.

(4) Upstream Diversion Channel

Upstream diversion channel is built in case where the catchments areas of both landfill site and outside areas are too large and the perimeter drains is insufficient to drain off the stormwater from the surrounding areas. Generally, a bunghole is dug at the upstream of the landfill site. Collected stormwater will either run through the pipe network located at the landfill bottom or channels that are installed to recirculate the collected water within the landfill site.

Table II-4 summarizes different types of drain for the application of stormwater drainage facility.

Table II-4 General Applications of Drain by Type

Type \ Drainage Channel	Perimeter Drain	Trench Drain in Landfill Site		Landfill Surface Drain	Upstream Diversion Channel
		Completed Landfill Section	Un-worked Landfill Section		
In-situ Concrete Channel	++				++
U-Ditch	++	++	++	++	
Corrugated Flume	++	++	++	++	
Corrugated Pipe			++		++
Box Culvert					++
Hume Pipe or Synthetic Polymer Pipe			++		++
Open Ditch and Sheet		+	+	+	
Soil Cement Channel		+		+	

Notes: "+" indicates a temporary measure.
"++" indicates full-scale measure.

3.3 Planning and Design of Stormwater Drainage Facility

A stormwater drainage facility shall be able to withstand the deformation conditions of the landfill sites and configuration due to the progress of landfilling activities for long period starting from its commencement of operation until the landfill completion.

It also needs to be well adapted to changes in drainage pattern due to the progress of construction works and landfilling activities.

It is necessary to plan and design an overall compatible stormwater drainage facility that is able to function at all time.

(1) Planning and Design Concepts

Stormwater drainage facility shall be able to withstand the deformation conditions of the landfill sites caused by the progress of landfilling activities. It is necessary to plan and design an overall compatible drainage that is able to function at all time, regardless of changes in drainage pattern due to the progress of construction works or landfilling activities.

For example, in the planning and design of perimeter drain at the beginning stage of landfill operation, it is important to examine thoroughly the design height and drainage system at the time of landfill completion so that the correct flow volume can be determined. Based on this information, the required cross-sectional area of the drains can be calculated and the most appropriate drainage layout plan can be established.

The drains may sometimes be clogged by accumulated sands, sediments and gravels.

Therefore, it is desirable to design the drains in a way that is easy to maintain and give ample cross-sectional areas so that to reduce accumulation of sediments, sands or gravels. Drains for discharging rainwater shall be separated from underground water drains.

On the other hand, the drain structure and cross-sectional area shall be designed with due consideration given to the topographical conditions. Under certain conditions, the access roads can also function as a stormwater drainage facility during rainfall. **Figure II-7** shows the general procedures for designing the stormwater drainage system.

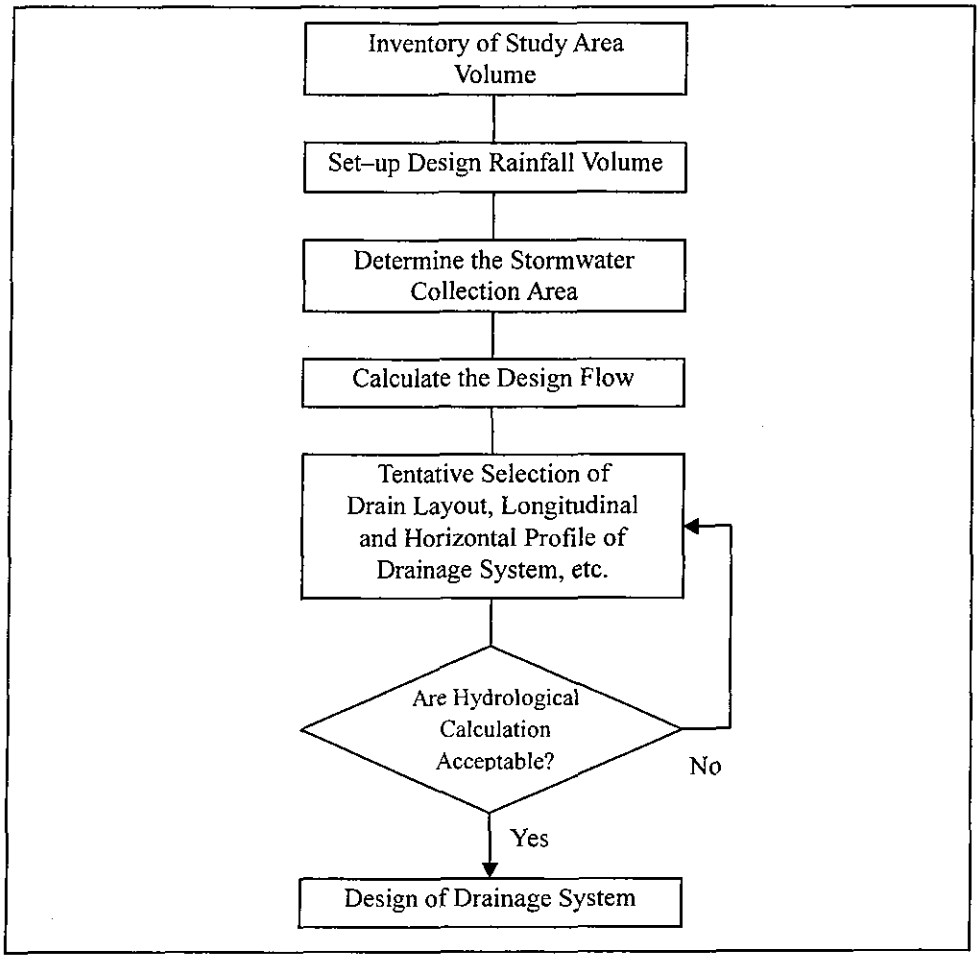


Figure II-7 Flowchart for Design of Stormwater Drainage System

(2) Calculation of Design Flow

The stormwater volume depends on rainfall intensity, catchments area, topography and land-use. It can be generally estimated from the following rational equation:

$$Q = 1/360\ C.\ I.\ A$$

Where,

Q = stormwater volume (m^3/sec)

C = Coefficient of flow (select appropriate volume in accordance with topography of landfill catchments area or vegetation, etc.)

I = Rainfall intensity (storm recurrence interval of 10 to 15 years (mm/hr))

A = Catchments area (ha)

Tables II-5 and **Table II-6** show the coefficient of flow for different land-use types.

Table II-5 Coefficient of Peak Flow by Landform

Topographical Condition	fp
Steep mountainous land	0.75 ~ 0.90
3rd Geological period mountain	0.70 ~ 0.80
Undulating land with vegetation	0.50 ~ 0.75
Flat farm land	0.45 ~ 0.60
Irrigated paddy field	0.70 ~ 0.80
River in mountain area	0.75 ~ 0.85
Stream in flat plain	0.45 ~ 0.75
Large river in flat plain	0.50 ~ 0.75

Table II-6 Coefficient of Peak Flow by Land-use Development

Stage of Land-use Development	fp	Remarks
Before development	0.6 ~ 0.7	More than 70% of catchments area is forest, plain, farmland
After development (1)	0.8	Catchments area with less than 40% of impermeable surface
After development (2)	0.9	Catchments area with more than 40% of impermeable surface

(3) Determination of Cross Sectional Area

Generally the cross section for open drain is either rectangular or elliptical. It is necessary to design for a slightly bigger cross sectional area to compensate the accumulation of sands, sediments and gravels by using the following equation:

$$S = Q/V$$

Where,

S = Cross-sectional area of flow (m^2)
Q = Discharge volume (m^3/sec)
V = Average flow velocity (m/sec)

The average flow velocity can be calculated by Manning's equation as:

$$V = 1/n\ R^{2/3}\ T^{1/2}$$

Where,

V = Average flow velocity (m/sec)
N = Manning's coefficient of roughness
T = Gradient of channel
R = Hydraulic Radius (m) = S/P

Where,

S = Cross-sectional area of flow (m^2)
P = Wetted perimeter (m)

Example on the design of stormwater drainage facility

Sample landfill site

Coefficient of flow	0.6
Rainfall intensity	100 mm/hr
Catchments area	5ha

Stormwater volume = 1 / 360 x 0.6 x 100 x 5 = 0.833 m^3/sec

In case the cast-in place concrete drainage (width of 0.8m, a depth of 0.5m, Manning's coefficient of roughness of 0.017, slopes of 1/100) is considered, the cross-sectional area of flow will be calculated as follows.

Hydraulic Radius = 0.4 / 1.8 = 0.222 m

Average flow velocity = $1 / 0.017 \times 0.222^{2/3} \times 0.01^{1/2} = 2.16$

Cross-sectional area of flow = 0.833 / 2.16 = 0.39 m^2

Thus the calculation result of the cross-sectional area of flow is just the same size with the considered drainage, the drainage can be adopted. (If the calculation result of the cross-sectional area of flow is widely different with the primary considered drainage, drainage size should be re-considered.)

Chapter 4 Leachate Collection Facility

4.1 Functions of Leachate Collection Facility

Leachate collection facility is aimed at collecting leachate generated from the landfill site, channelling it to a pre-determined facility for treatment before discharging it to the environment. It also serves to supply air into the landfilled waste layers through the collection pipes for the semi aerobic sanitary landfill.

The general function of leachate collection facility is to quickly collect and channel the leachate generated from the landfilled waste layers to the leachate treatment facility. The leachate volume generated in a landfill shall be kept minimum and removed immediately to the leachate treatment facility, so that there will be no trapped leachate in the landfill site. This is important to ensure that the water pressure acting on the liner facility and landfilled waste retaining facility is minimized. In other words, the leachate collection facility in one of the very important factors has to be considered in the selection of liner facility.

In the case of semi aerobic landfill system, the leachate collection facility is also serves to supply air into the landfilled waste layers and subsequently enhance the entire gas venting processes.

4.2 Components of Leachate Collection Facility

Leachate collection facility consists of collection pipes, leachate retention pits, leachate control valves, etc. It needs to be conformed to the landfill conditions such as the topography of the landfill bottom or landfill structure. Ultimately it shall be able to collect and discharge leachate effectively.

The components of a leachate collection facility are depending on the landfill types and structures. General conceptual layout plans for leachate collection facility are shown in **Figure II-8** and **Figure II-9** below.

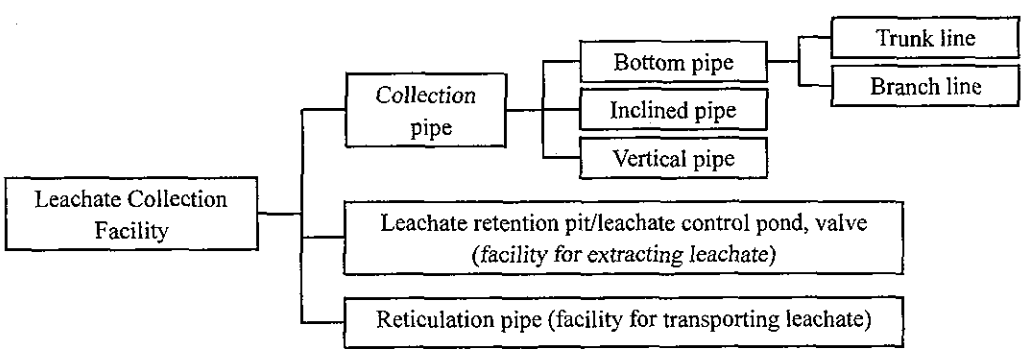


Figure II-8 The conceptual layout plan for leachate collection facility

In the planning of water retention pit and reticulation pipe, it is necessary to consider the division of functions and the compatibility of these facilities with leachate extracting and reticulation facilities.

(1) Collection Pipes

a) Bottom Pipes

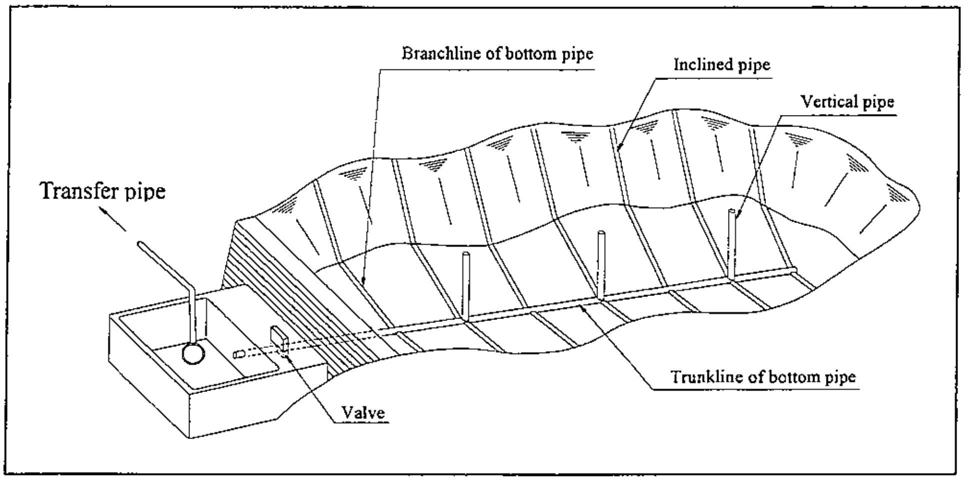
Ducting placed at the bottom of landfill sites for leachate collection. It comprises of trunk and branch pipes that are installed at a gradient to enable natural flow potential.

b) Inclined Pipes

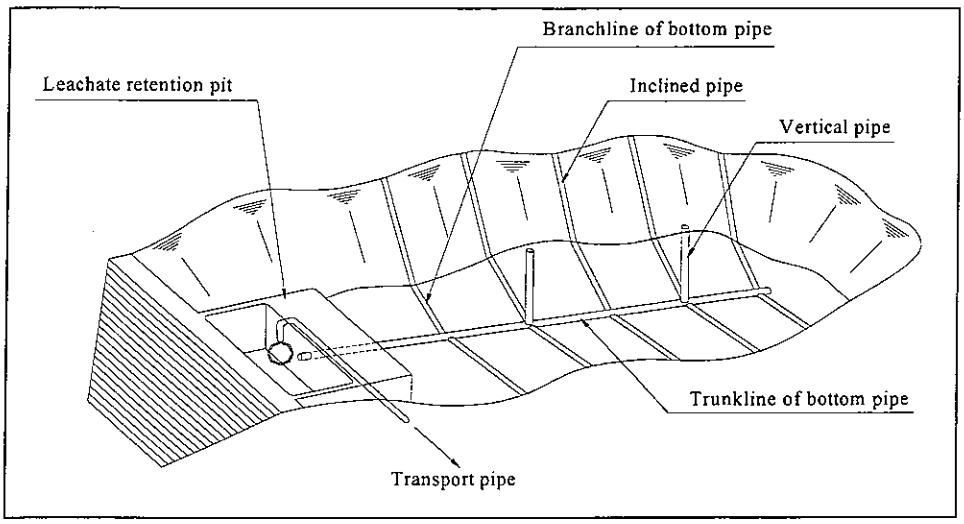
Placed along the slope of the landfill sites and connected to collection pipes at the landfill bottom. Preferred to vertical drainage pipe which shall be avoided from the aspect of intermediate covering. It also serves as gas vent.

c) Vertical Pipes

Leachate collection pipes placed vertically in the landfill. The heights of the pipes will be extended vertically as landfilling continues. The bottom ends of the vertical pipes are connected with the bottom pipes. It can also serve as gas vent like the inclined pipes.



A. Retention Pit Outside Landfill



B. Retention Pit Inside Landfill

Figure II-9 Concept of Leachate Collection Facility

(2) Leachate Retention Pits and Valves

Leachate collection facility shall be placed with considerations on the topographical conditions of the landfill bottom. It shall be able to function effectively in collecting and discharging the leachate from the landfill waste layers without clogging of the collection pipes.

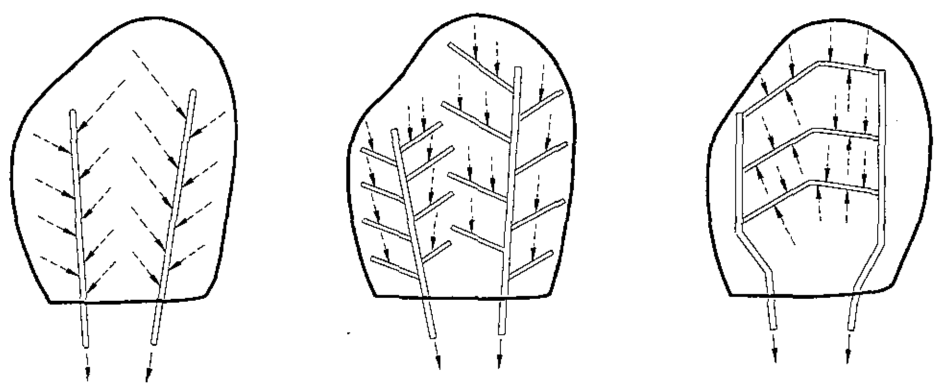
Retention pit is the facility located at the terminal of the collection pipes from where leachate is pumped out. The pit may be located inside or outside the landfill site. The selection of location is related to leachate treatment facility, retention ditch, topographical and site conditions etc.

Valves are required if the leachate retention pits are located out of the landfill site. Leachate flow is regulated by the valves, care shall be taken to prevent the formation of "scales" on the valves. The valves shall be maintained and inspected regularly.

4.3 General Structure of Leachate Collection Facility

(1) Layout

Depending on the topography of the landfill site and landfilling method, the layout plans for subterranean leachate collection pipes can be designed as shown in **Figure II-10**.



(i) Straight Line Pattern (ii) Herring Bone Pattern (iii) Ladder Pattern

Figure II-10 Layout Plans for Bottom Pipe

For straight line pattern, one or several pipes are installed linearly and if the ground surface is very wide, several pipes can be laid out in parallel.

The herring bone pattern is formed by connecting branch pipes to the main pipes. Leachate is collected by branch pipes and discharged by the main pipes. Several sets of collection pipes can be arranged in the herring bone pattern for a large-scale landfill site.

The ladder pattern is commonly used on flat landfill site where it is difficult to achieve the required cross fall.

The layout of bottom collection pipes must be located based on consideration given to the permeability of the landfilled waste and buffer sand layer on the liner, size as well as the topography of landfill site. Furthermore, for a semi-aerobic sanitary landfill system, the ability of the leachate collection facility to bring in outside air into the waste layers to enrich the aerobic conditions is also an important criterion.

In general, spacing between the bottom collection pipes is depending on the catchments area and whether it is a sectioned or separated landfill site. Experience in Japan shows a spacing of 20-30m is desirable. As for inclined collection pipes, the spacing can be set further apart, normally about twice that for the bottom collection pipes. Vertical collection pipes can also be treated in the same manner as the inclined collection pipes placed on cut surface. Nevertheless, in determining the pipe spacing, consideration shall be given to the influence of landfilling work as well as the permeability of landfilled wastes.

(2) Materials

a) Collection Pipes

The types of material chosen for collection pipes are crucial to ensure sufficient structural strength to accommodate the pressure at various depth and also anti-corrosive to the leachate. Generally, perforated Hume pipes or those made of synthetic polymer are commonly used as collection pipes. The perforated Hume pipes are very rigid, while the synthetic polymer pipes are highly flexible. Therefore, the choice shall be made based on a comparison of their respective characteristics with the landfill site conditions.

The pores on the perforated surface of the collection pipes can be clogged up easily. If packed gravels are used as collection pipes, their diameter shall be at least twice of the perforated pipes. It is advantageous to place packed gravels surrounding a perforated pipe as filter materials.

Table II-7 summarizes the characteristics of various types of collection pipes.

Table II-7 Types and Characteristics of Collection Pipe

Type of Pipe	General Diameter (mm)	Characteristics
Perforated Hume Pipe	150 - 3,000	Commonly used as collection and discharge pipes. Very rigid structure and suitable for cases where deformation of pipe is not tolerable.
Perforated Polymer Pipe Reinforced Plastic Pipe (FRP and FROM pipes) Harden Polyethylene Pipe Harden PVC Pipe	100 - 1,500	Commonly used as collection and discharge pipes. Very flexible and suitable for cases where ground subsidence is expected. Generally resistive to corrosion. Light and relatively easy to install.
Permeable Concrete Pipe	100 - 700	Commonly used as collection pipes but pores can be easily clogged up.
Permeable Synthetic Polymer Pipe	100 - 600	Commonly used as collection pipes depending on material. Pores can be easily clogged up.
Packed Gravels		Commonly used in small-scale landfill site as collection pipes. To compensate for clogging, diameter shall be more than twice that of perforated pipes. Preferably used together with perforated pipes

b) Filter Materials

The filter materials are the materials used to cover the surrounding of the collection pipes in order to ensure its functionality. Pebbles, gravels and construction debris are normally used.

In selecting the type of filter material to use, the following points shall be considered:

- Grain size distribution and diameter of the select materials shall be large enough so that it does not clogged up easily by sands, wastes or scales.
- Filter materials also act as backfill materials, therefore, it is desirable that it has sufficient strength, low compressibility and high stability.

Based on the abovementioned, pebbles, gravels or construction debris of 50mm to 150mm diameter are suitable as filter materials. It is not desirable to apply a layer of sand or buffer blanket over the filter materials because their pores can be clogged up easily by the sands.

(3) Structures

a) Bottom Pipes

The bottom pipes are perforated pipes or packed gravels which are buried together with filter materials to prevent clogging. In order to prevent deterioration of the function of filter materials, the thickness of the filter layer shall be more than 50cm from the ground level (or above the protective soils cover on the liner). The efficiency of the collection pipes can be enhanced if proper filter materials are used.

Figure II-11 shows the typical design examples of bottom collection pipe.

The width of filter materials shall be three times more than the diameter of the pipe in order to ensure its functionality and to reduce direct vertical loading on the collection pipes. In the presence of liner, extra care shall be taken to ensure that the gravels and pebbles do not touch the liner directly. A protective layer of buffer blanket, sands or soil cover can be applied.

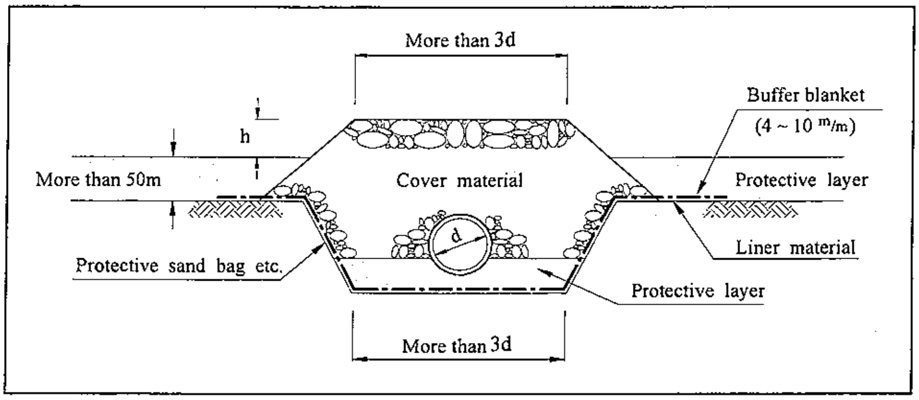
b) Inclined Pipe

It is relatively difficult to fix the filter materials around the inclined pipes placed on the cut-section. Plastic or anti-corrosive netting can be used to fix the shape of the filter materials. On a gentle slope, packed gravels can be used if measures to prevent the distortion of its shape are taken when packing the gravels. In addition, synthetic polymer material or permeable materials are also commonly used.

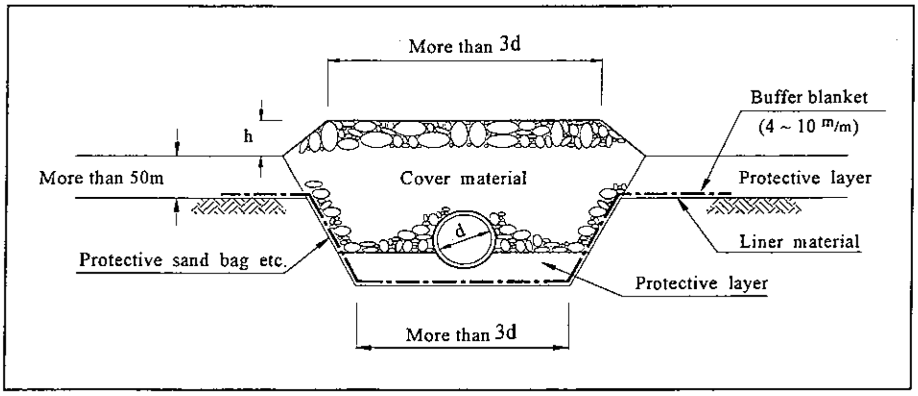
c) Vertical Pipe

In order for the vertical pipe to stand upright, the base shall be fixed and it is built up by packing filter materials around the pipe as landfilling works progress. Generally, the initial height of the pipe is recommended to be 4 to 5m.

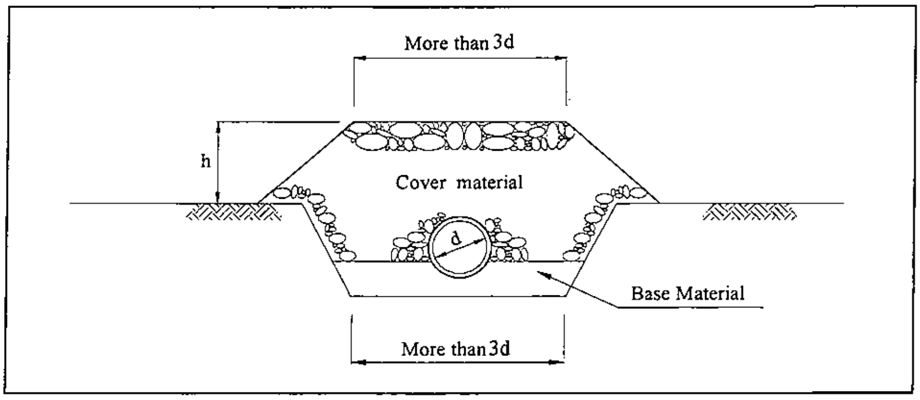
Leachate collected by the vertical pipe is discharged by the bottom pipes. The vertical pipes can be located directly above the bottom pipes or connected to it in such a way to expedite the discharge of leachate. **Figure II-12** shows an example for the design of vertical pipe.



A. WITH COVER MATERIAL



B. WITH PROCTECTIVE LAYER



C. WITHOUT SURFACE LINER

Figure II-11 Typical Design of Bottom Pipe

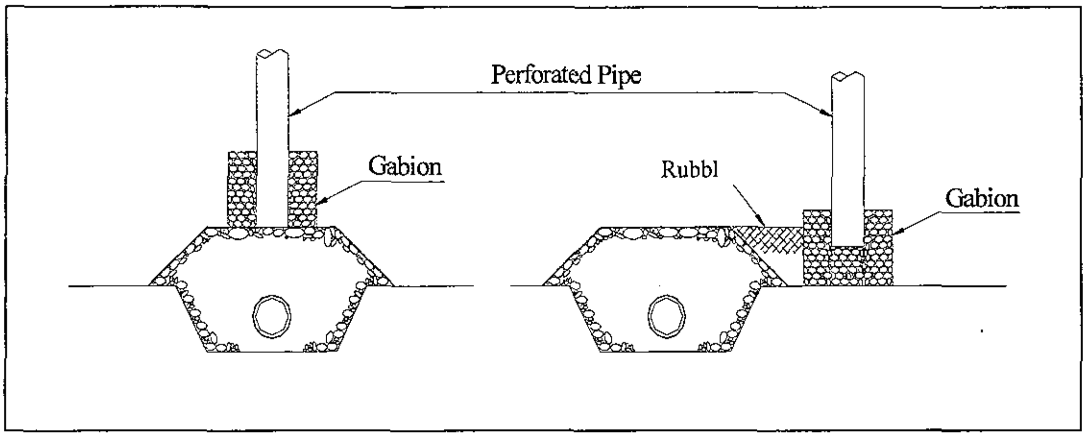


Figure II-12 Example of Vertical Pipe

4.4 Design Flow and Cross Sectional Area

It is necessary to determine the capacity of leachate collection facility based on leachate volume calculated by taking into account factors such as the climatic and topographic conditions, locations of other main facilities etc.

The cross-sectional area of collection pipe shall be determined not only depending on the size of catchments area but also the need to supply air into the waste layers particularly for the semi aerobic landfill system.

However, it is difficult to estimate the amount of air required. It is thus necessary to select a diameter size which is large enough to allow passage of air through the pipes.

(1) Design Flow

Under common conditions, the sources of leachate generation are basically waste moisture contents and rainfall. Generally, the effect of rainfall on leachate generation is tremendously large. Therefore, only the leachate generated by rainfall are considered and discussed in this section.

The size of leachate treatment facility is determined by the average daily discharge volume. However, leachate collection facility has to respond directly to the discharge volume. Sometimes its capacity may not be sufficient if the design is based on the average daily discharge volume.

Therefore, the design flow shall be done so that the leachate collection facility is able to handle high intensity of rainfall over a short period as shown in calculation for stormwater drainage facility.

An approximate method to express the relationship between rainfall and discharge volume is given by the Rational Equation. The design flow can be determined using the rainfall intensity and coefficient of discharge at the landfill site.

(2) Rainfall Intensity and Coefficient of Discharge

The rainfall catchments area shall be kept as small as possible by applying section landfilling in a large landfill site. Coefficient of discharge shall be kept as large as possible because the time for leachate to remain in the landfill site shall be as short as possible. Coefficient of discharge of 0.6 ~ 0.7 can be used if rainfall intensity is about 30-50mm/hr. Thus, the design flow becomes Qmax < 0.06 ~ 0.1m^3 /(sec-ha).

For a design flow of 0.06m^3/sec, if the main leachate collection pipe made of 600mm diameter Hume pipe is placed at a gradient of 1%, then the discharge volume will be 10% of the full pipe capacity (about 0.6m^3/sec) and its water depth is about 120mm or about 20% of the pipe's diameter.

(3) Cross Sectional Area

The cross-sectional area of the leachate collection pipes shall include consideration for air and gas circulation besides the function of discharging leachate. For perforated pipes, it is sufficient to design the diameter to be 50% above that required by the design flow because the cross-sectional areas required by air and gas are assumed to be provided by the top portion of the pipe's cross-sectional area.

Generally, main leachate collection pipes shall have diameters of larger than 600mm and branch pipes with diameters of more than 200mm.

4.5 Loading Conditions

Leachate collection pipes are under the pressures of waste and earth loads both in vertical and horizontal directions, so that it must be designed to suit with these pressure conditions.

Generally, leachate collection pipes have the following characteristics:

- Pipes are buried very deep under the high embankment. However, the actual depth depends on topography and types of landfill.
- The loadings on the collection pipes are changing at all time because the landfilled layers are being compacted continuously when landfilling activities progress.
- The pipes are able to discharge leachate with strong corrosive properties.
- Larger pipes shall be used to ensure smooth discharge of leachate and proper function of semi aerobic landfill system.
- The pipes may sometimes have to be constructed on weak foundation.

The collection pipes shall be designed under the loading conditions determined by landfilled layer pressure acting vertically and laterally.

(1) Vertical Force

The vertical force from landfilled layer varies depending on how the pipe is installed. If the pipes are buried inside a dug-out ditch, subsidence of the earth above the ditch can be prevented by frictional forces on both sides of the ditch. In this case the loading on the pipes is reduced. On the other hand, if the pipes are placed on the ground and then covered by embankment, subsidence of embankment can be prevented by the pipes. The pipes will experience not only the dead load of the cover earth but also frictional force on both sides. Vertical force acting on the pipes varies depending on its installation method and the conditions of backfill materials. The gravels placed on both sides of the pipes shall be compacted.

(2) Lateral Force

When the filter materials surrounding a pipe are well compacted, lateral static forces and ground reaction forces will act on the pipes besides the vertical force. These forces act to constraint the deformation caused by the vertical force and causes a reduction in bending moment in the pipe structure. For rigid pipes, lateral forces can be ignored if they are buried at shallow depth. However, in most landfill sites, the pipes are buried very deep and thus the calculated bending moment acting on the pipe will cause excessive design if the lateral force is not taken into consideration.

4.6 Other Aspects in Planning

When planning and designing the leachate collection facility, it is also necessary to consider the structures of sealing work such as the liner facility, as well as the operation and maintenance works.

(1) Leachate Collection and Liner Facility

Leachate collection facility shall be planned and designed for landfill site with vertical liner facility if there is an influx of spring water or groundwater from the surrounding area.

In the case of a landfill site with surface liner facility, the leachate collection facility shall be separated from the underground water drainage facility. When constructing the leachate collection pipes above the liner facility, utmost care shall be taken to prevent damage to the liner. Generally, a protective layer of buffer blanket of 4 to 10mm thick is placed on top of the liner.

(2) Maintenance and Operation

The inspection, maintenance and repair of the leachate collection pipes are very difficult as landfilling work progresses. Therefore, impervious wastes or ashes shall not be dumped around the pipes by all means. During operation, sufficient depth of landfilled layer is necessary before beginning to compact the wastes in order to avoid damage caused by heavy machinery.

Chapter 5 Liner Facility

5.1 Functions of Liner Facility

Liner facility is installed to prevent pollution of public water bodies or groundwater by leachate discharged from the landfill site. It also prevents the increase of leachate volume caused by inflow of surrounding groundwater into the landfill site.

Liner facility is installed in a landfill site to prevent pollution of public water bodies or underground water by leachate discharged from the landfill site. In other words, it functions to mitigate adverse impacts of such pollution to the surrounding areas. It also prevents the increase of leachate volume caused by inflow of surrounding groundwater into the landfill site.

It is important to plan and design liner facility with high level of suitability based on topographical and subterranean characteristics. Common design concept is to have a liner facility which does not allow the discharge of leachate from the landfill site into the outside area by utilizing the characteristics of the topography at the landfill site, the permeability of the ground as well as characteristics of groundwater

Stormwater drainage and leachate collection facilities complement the function of liner facility. The stormwater drainage facility eliminates rainwater from entering the landfilled wastes and thereby reduces the volume of leachate generated. The leachate collection facility drains away the leachate generated quickly. Therefore, the ability of these facilities to enhance the function of the liner facility shall be considered at the design stage.

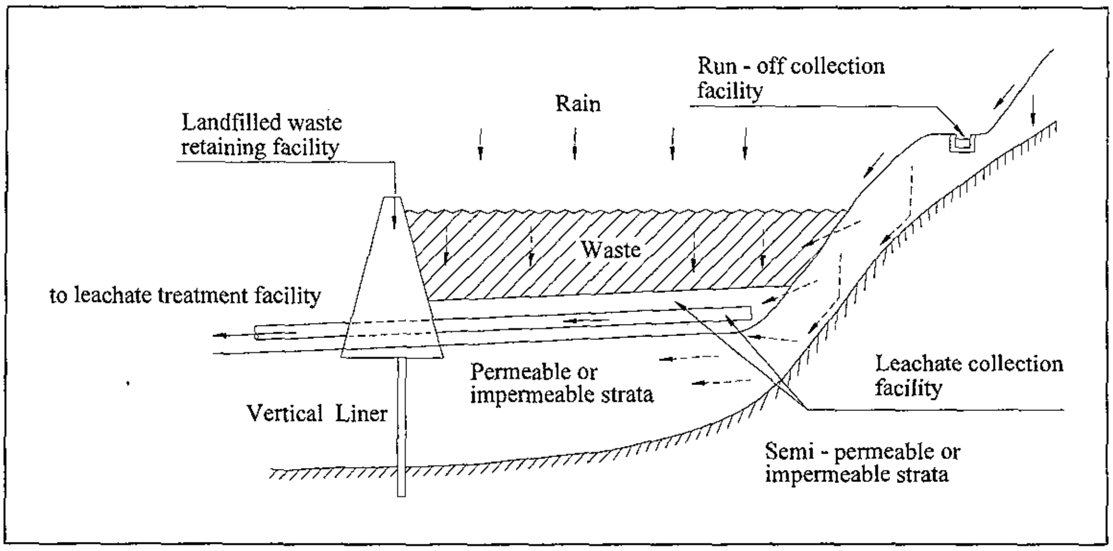
5.2 Types of Liner Facility

The structures and types of liner facility used shall be conformed to the topographical and geological conditions of the landfill site, soil conditions, groundwater conditions, as well as the location of leachate collection facility.

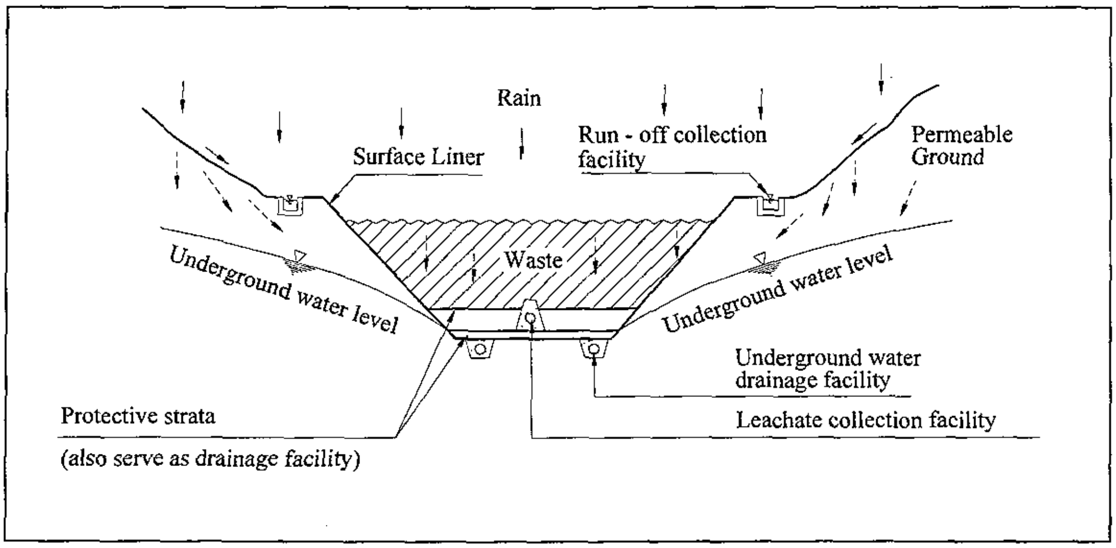
(1) Classification of Liner Facility

Liner facility can be classified according to the structures and types of material into surface liner facility and vertical liner facility as illustrated in **Figure II-13**.

The surface liner facility is applied to landfill sites or ground with high coefficient of permeability. The whole landfill areas are covered with a waterproof material and in principle the construction of drainage facility for groundwater is necessary. Therefore it is important to ensure that the drainage facility does not crack due to displacement or subsidence of the landfill structures.



Surface Liner Facility



Vertical Liner Facility

Figure II-13 Concepts of Liner Facility

Vertical liner facility is suitable in areas where there is an impervious layer such as rock or harden clay that spread horizontally over the landfill site. A vertical or slant barrier is constructed to make the leachate or groundwater that seeps along a longer route and finally getting trapped between the landfilled layers and the impervious layer. It is common to make the retaining facility and the foundation of a sanitary landfill system at the valley to function as liner facility as well. This system generally does not require drainage system for groundwater.

Table II-8 shows a comparison between vertical and surface liner facility.

Table II-8 Comparison between Surface and Vertical Liner Facility

Item	Surface Liner Facility	Vertical Liner Facility
Suitable Application	Presence of suitable foundation in the landfill site which can be covered by impermeable material	Presence of horizontal layer in the ground
Groundwater Drainage Facility	Generally required	Not required
Ease of Inspection	Although the liner facility can be inspected visually during construction it is difficult to inspect once landfill has begun	Difficult to inspect because of being buried
Cost Effectiveness	Construction cost per unit area is cheap but because of the need to cover the whole surface of the landfill site, its total cost is high	Construction cost per unit area of liner facility is high, but it is insignificant compared to the overall cost
Maintenance	Possible before landfilling after which it is difficult	Difficult but is possible to strengthen the function of liner facility

(2) Selection of Liner Facility

Generally, the important criteria for selecting type of liner facility or whether such facility is required are depending on the geological conditions of the landfill site as well as the permeability of the ground. These include the ground characteristics, location and level of aquifer, direction of flow and volume of underground water, groundwater usage condition such as wells etc.

Some important points of the criteria are summarized as follows:

- A liner facility is necessary if the soil foundation has a coefficient of permeability of higher than 10^{-5} cm/s. However, even if the permeability of the foundation has a value lower than this figure, it is important to confirm that the layer is sufficiently thick to function as a liner facility.
- If a spring exists, its location and size shall be investigated. When installing a surface liner facility, drainage system for the spring shall be installed downstream to the liner facility. It is not recommended to carry out landfilling activities over an area with large volume of spring water.
- Some pollutants can be removed by passing through the soil. Wide spread pollution can be prevented with proper selection of liner facility based on consideration on the characteristics of the surrounding soils.
- The most common surface liner facility is using the liner sheets. Other methods are such as using "Shotcrete" (sprayed concrete), earth lining made in compacted clay or loan soil and using soil cement or asphalt etc. Selection of method to be used shall be determined depending on the topographical and geological conditions, underground water, waste characteristics, landfilling method, landfill age, construction costs, etc.
- For surface liner facility, groundwater drainage facility shall be installed beneath the liner facility in order to reduce the uplift by the groundwater. Perforated Hume pipe of size 15 to 30cm diameter are commonly used.

- Substantial subsidence of liner facility is expected if it is installed on a weak foundation. In such case, clay liner and soil cement are not suitable because it is inelastic. On the other hand, the waterproof liner sheets shall be used because the elasticity of the waterproof sheet is large enabling it to withstand a certain degree of subsidence.
- For rock foundation, grouting is the normal method to install a vertical liner facility while a waterproof sheet is normally used on a soil foundation. If the soil foundation has alternating layers of clay and sand, then a combination of vertical liner facility using steel sheet piling and a subterranean clay liner is normally adopted.

5.3 Structural Characteristics and Construction of Liner Facility

When liner facility is designed and constructed, it is necessary to consider the structural characteristics of the types and materials for liner facility.

The structural characteristics of surface and vertical liner facility are different not only because of different material used but even if the same material is used, the water proofing function will also be different.

Design and implementation of the proposed liner facility shall reflect its characteristics and the following factors shall be considered:

(1) Thickness of Liner System and its Durability

The thickness of a liner facility shall be determined in accordance with its classification, quality of materials, construction standard, subterranean condition, joint method, corrosion and durability. In general, the values given in **Table II-9** are applicable.

It is prudent to install a supportive layer if the liner facility is expected to be exposed to sunlight, rainfall, etc. for over a long period. It is important to examine the tolerance level of the liner sheet to sharp objects and oil. As for steel sheet piling, the resistively to corrosion shall be examined.

(2) Required Function of the Earth Lining

The required function of the earth lining is as follows:

- Long-term stability (low-contents of an organic matter and long-term durability)
- Appropriate particle size distribution and 8% or more of fine particle ratio
- High-sealing ability (coefficient of permeability : less than $1x10^{-6}$cm/s , thickness of layer : more than 50cm)
- Easy procurement of enough soil as the earth lining

When it is difficult to obtain the soil material which fulfils the above-mentioned item by itself, it is necessary to adjust the above item by mixing a stable material such as bentonite and the cement.

Table II-9 Thickness of Liner Facility

Method/Item			Factors to be Considered	Normal Thickness	Remarks
Surface Liner Facility		Earth Lining	* Grain size distribution, coefficient of permeability * Compaction, level of workmanship * Water pressure on the back, stability of sludge	1m and above	Ensure that there is no resistance to tension and bending
Surface Liner Facility	Sheet Liner	Synthetic Rubber	* Uneven groundwork * Application of protective material and grain size * Type of waste (Sharp objects, compressibility, etc.)	1.5mm	In principle, a protective layer is installed between the liner and waste Liner will be easily damaged if workmanship is bad
Surface Liner Facility	Sheet Liner	Synthetic Polymer	- Same as above -	1.5mm	- Same as above -
Surface Liner Facility	Sheet Liner	Asphalt Sheet	* Uneven groundwork * Covering of groundwork with "Shotcrete", etc. * Level of workmanship * Application of protective strata on surface	3 ~ 5mm	Need to confirm whether material can withstand leachate
Surface Liner Facility		Pavement	* Coefficient of permeability * Level of workmanship • Water pressure on the back	5 ~ 10cm and above	Ensure that resistance to tension and bending is minimum. Lighter than earth lining. Necessary to consider water pressure on the back Necessary to confirm whether material can withstand leachate
Vertical Liner Facility		Care of Earth Dam	• Grain distribution, coefficient of permeability * Dynamic water pressure (Piping phenomenon) * Composition (Water content during construction, compacting machinery)	About 1 ~ 3m (Thicker at the lower level)	Use of concrete core is very rare
Vertical Liner Facility		Steel Sheet Pile	* Corrosion * Workability (Rigidity during installation)	3 – 30mm	Several anti-corrosion measures are available
Vertical Liner Facility	Grouting	Seepage Method	* Limit of permeability (grain size of material) * Bore hole interval	1 - 3m	Generally grouting is made on 2 to 3 rows of pipe
Vertical Liner Facility	Grouting	High Pressure Injection Method	* Strength of foundation (M-value) * Grain size * Jet pressure	0.3 ~ 1m	The finished thickness varies greatly with soil condition and foundation strength. Heed to be confirmed by pilot test
Vertical Liner Facility		Excavation and Laying of Sheet Liner	* Workability	1.5mm	Will last longer than surface liner in the absence of ultra violet rays
Vertical Liner Facility		Continuous Subterranean Wall	* Coefficient of permeability of material * Method of joining, construction joint * Width of construction equipment	5 ~ 6cm and above	Shape of excavation depends on the width of construction equipment. Thickness is often determined by coefficient of permeability in the case of mixing with local materials and thickness of buried steel sheets

(3) Groundwork for Surface Liner Facility

The groundwork for surface liner facility besides being the foundation supporting the landfill dead load and leachate water pressure, is also the protective base of the entire facility. The preparation of groundwork has great impact on the water proofing ability of the liner facility, especially for liner sheets. This activity is the most important process in the installation of the liner facility. The following shall be noted:

a) Groundwork before laying of liner sheets

The groundwork before laying of liner sheets is generally removed of angular stones and sharp objects, sufficiently compacted and finished up the ground to be flat and smooth. Undulating surface can easily cause damage to the liner sheets. If suitable groundwork cannot be achieved, a layer of non-fabric blanket between the liner sheets and the groundwork is recommended.

It may be necessary to apply a layer of soil cement on the slope in order to strengthen its compaction effect. Sometimes layers of protective sheets such as nylon canvas or non-fabric blanket are laid over the uneven surface of rocky foundation or exposed rocks.

As for the bottom of the landfill which is expected to be compacted, it is necessary to apply a layer of sand (standard thickness of about 10 to 20cm) if the bottom surface area is wide and the soil foundation contains many stones.

b) Measures for uplift water pressure

Groundwater drainage facility such as under-drain shall be installed to counteract the water pressure caused by groundwater or spring water.

The following standards can be applied to drainage pipes to be installed on the slope to counteract water seepage from the sides of a cut or embankment.

- Drain pipe diameter = 100 ~ 300mm
- Gradient = 1% ~ 2%
- Interval = 20 ~ 40m

c) Measures for gas pressure

Gas vent shall be installed to release the gaseous uplift generated by decomposition of wastes as well as other air forced out by the influx of water seepage during a heavy storm. **Figure II-14** shows examples of gas vent.

Generally gas vents are connected directly from the surface to the subterranean drains or placed above it at an interval of about 10 ~ 30m using perforated PVC pipes of 20 ~ 50mm diameter.

In wide landfill areas where the location of putrefactive wastes is known, the landfill foundation can be made up with a gradient of 1 ~ 2% or gas vent can be laid on the bottom.

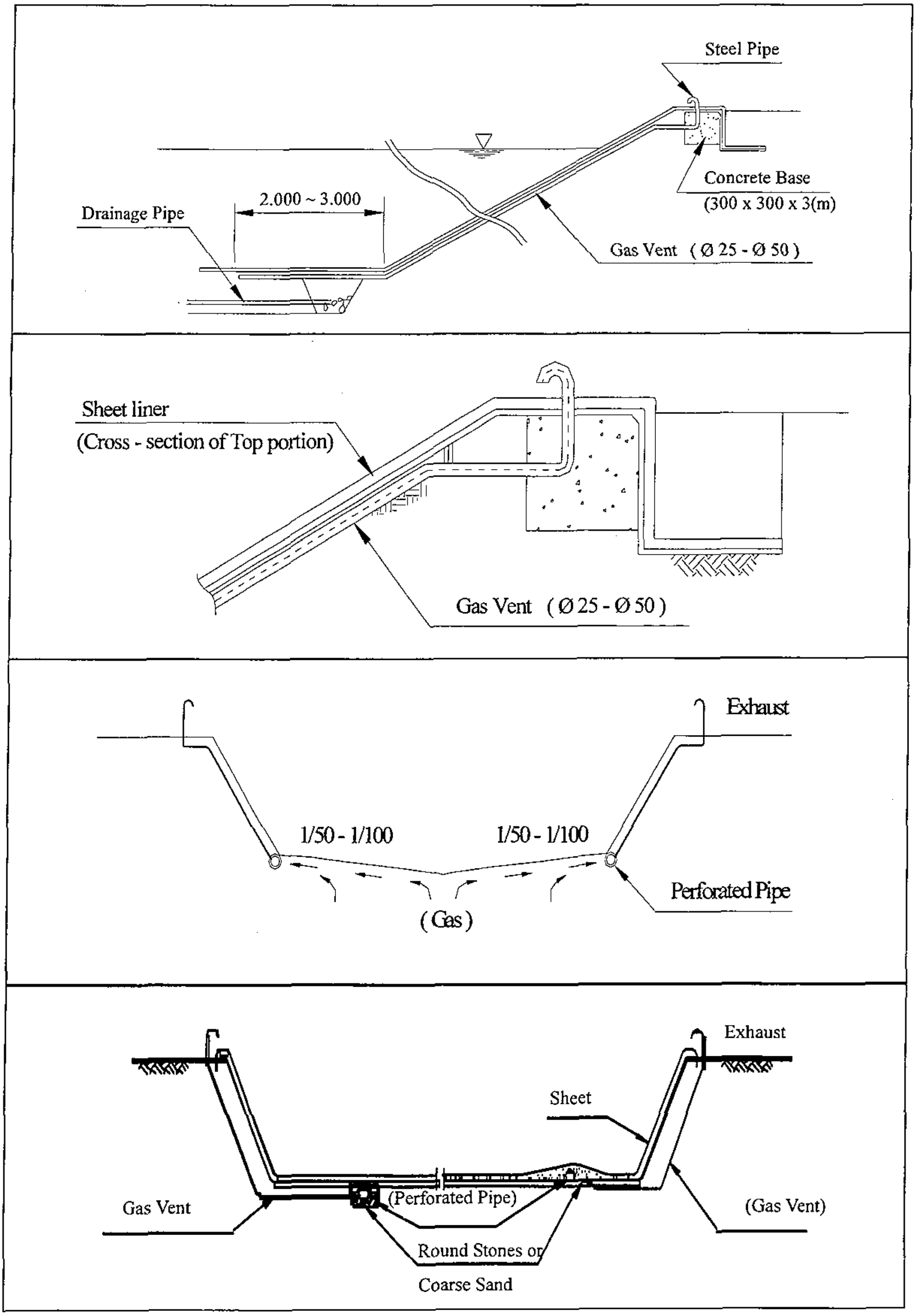


Figure II-14 Installation of Gas Vent in Landfill with Liner Facility

d) Measures for Weed

Vegetation on the groundwork shall be removed either through physical means or applying weed killer. It is ideal to sterilize the ground before applying the groundwork if possible.

e) Measures for Damage

A completed groundwork area shall be prevented from being disturbed by wind, rain or footsteps and track marks of vehicles before the laying of the sheet liner.

It is very difficult to repair any damage caused by poor preparation of groundwork for a liner facility. Therefore utmost care shall be taken throughout the entire process of liner groundwork preparation as well as final implementation.

Table II-10 summarizes the causes of liner facility damage and the appropriate preventive countermeasures.

Table II-10 Causes of Damage to Liner Facility

Cause of Damage	Why it Happened?	Countermeasures
Sharp objects, Foreign bodies	Excessive stress due to landfill layer pressure or leachate pressure acting at a point	Removed sharp objects, apply a layer of sand or protective concrete
Ground Settlement	Uneven settlement of ground due to landfill layer pressure or leachate pressure cause great strain at local points	Replace ground with good material and make it well contacted
Insufficient Base Support	Damage to groundwork due to heavy loading at local point attributed to landfill equipment	Replace ground with good material. Apply a layer of sand and make it well compacted
Displacement of Ground Foundation	Upheaval of ground due to displacement caused by earthquake, etc.	Install measures which are able to absorb strain caused by sudden movement in geological condition
Uplift	Upheaval due to back water pressure. The force generated can cause damage to liner facility	Install underground water drainage facility such as sand mat, culvert, etc.

(4) In-situ Joining of Liner Sheets

In using a liner sheets, it is necessary to join several sheets in-situ on the landfill site to suit with the site topography. For vertical liner facility, pieces of sheet piles may need to be joined together. The joints for concrete works are also made in-situ. These joining points are the weakest part for liner facility and therefore, it is necessary to examine the treatment of joints when selecting a liner facility.

- The structural strength of the joined portion after deteriorates and concentration of stress at the joints will cause damage. Therefore the joints shall not be located where the stress is concentrated.
- Joints can also be damaged by concentration of strain. Therefore, they shall not be located where strain is large, for example uneven subsidence of ground, etc.
- For earth liner, the occurrence of piping is disastrous. The joints will be weak if the two pieces of clay liner are not constructed simultaneously. A thicker layer of earth liner shall be constructed at places where water pressure is expected to be large.

(5) Measures for Protection of Liner Facility

Vertical liner facility such as grouting and sheet piling will not deteriorate or get damaged easily if it is installed under strict control and high workmanship.

However, the situation is different for surface liner facility because it can be damaged during landfilling and the consequence is serious. In order to protect the liner sheets, raw wastes are not supposed to be dumped directly on the sheets. A layer of protection sand cover of about 30 to 50mm thick shall be overlaid on the liner sheets. With the protection sand cover, the adverse impacts from collection vehicles and heavy equipment such as spreader and compactors will also be minimized. Materials with high coefficient of permeability such as sands shall be chosen as the protection layer to ensure efficient leachate collection.

During the landfilling work, the liner facility is tended to be damaged by the operation of a heavy industrial machine, such as the sudden turning-over of the bulldozer, the touch by the blade and so on. In order to avoid damage of the liner facility, it is necessary to be careful about landfilling works. When collection vehicles or heavy machinery run on the liner facility, it is important to run on the landfilled layer which has 50cm or more thickness from the surface of the liner protection sand layer. When dumping wastes from a collection vehicle, it should not dump directly on protection sand, but should down on the sufficient depth of landfilled layer.

Table II-11 shows the main protective measures for surface liner facility (liner sheets).

Table II-11 Protection for Liner Facility (Liner sheets)

Stage	Examination Item	Examination Content	Countermeasures
Design	* Stability of physical aspect	* Against ultra-violet ray * Damage due to stress and strain * Fluctuation in permeability	* Install protective layer * Remove concentration of stress and strain * Additional protection through grouting, etc.
Installation	* Characteristics of things coming into contact with surface of sheet * Construction vehicles	* Pointed objects in the protective layer * Condition of leachate collection facility * Movement lines of bulldozer, dump trucks, etc.	* Apply a layer of sand, limitation of maximum grain size * Install buffer blanket
Landfilling	* Damage due to spreading of waste * Deterioration of properties of matter * Animals and vegetables	* Pointed or sharp objects among wastes * Damage caused by land-filling equipment * Deterioration due to ultra-violet ray, expansion and contraction, etc, * Violation by animals and vegetation growth	* Control waste type, limitation of maximum size * Control landfilling wastes * Install protective layer * Strengthen protective layer * Install fence, remove roots of plants, etc.
Ultimate Land-use	* Increased loading * Pile foundation	* Settlement * Measure to prevent damage to sheet liner	* Distribute loading * Grouting and change configuration of foundation

5.4 Underground Water Drainage Facility

Underground water drainage facility is installed when necessary to protect the function of liner facility. The facility shall be determined by considering locations and amount of groundwater discharge, topographic condition of landfill bottom, etc.

(1) Functions of Underground Water Drainage Facility

If the underground or spring water is not removed, the surface liner facility may be damaged by the uplift pressures generated by the water or gas under the liner.

The raise in underground water level in poor soil condition area could also cause the loosening of mountain surface and slope failure. Therefore, underground drainage facility plays an important role in maintaining the landfill stability. It shall function effectively to expel water and gas from the landfill site.

(2) Structure

Generally, underground water drainage facility consists of a buried perforated pipe covered with a protective layer of gravels or filter materials such as sand. The axis of the main pipe is placed in the direction of water flow and branch pipes are connected longitudinal to it. In order to ensure that the collapse of one section will not disrupt its function, normally the main pipe consists of several pipes buried along each other. If gas production is expected, a gradient shall be formed at the bottom and gas vents shall be installed.

The design loading of underground water drainage facility shall consider landfill layer pressures, life load and reaction from the foundation. Loading conditions also vary with the layout of piping network and elasticity of the pipe structures.

Figure II-15 shows a typical cross-section of a underground water drainage facility.

(3) Size and Layout

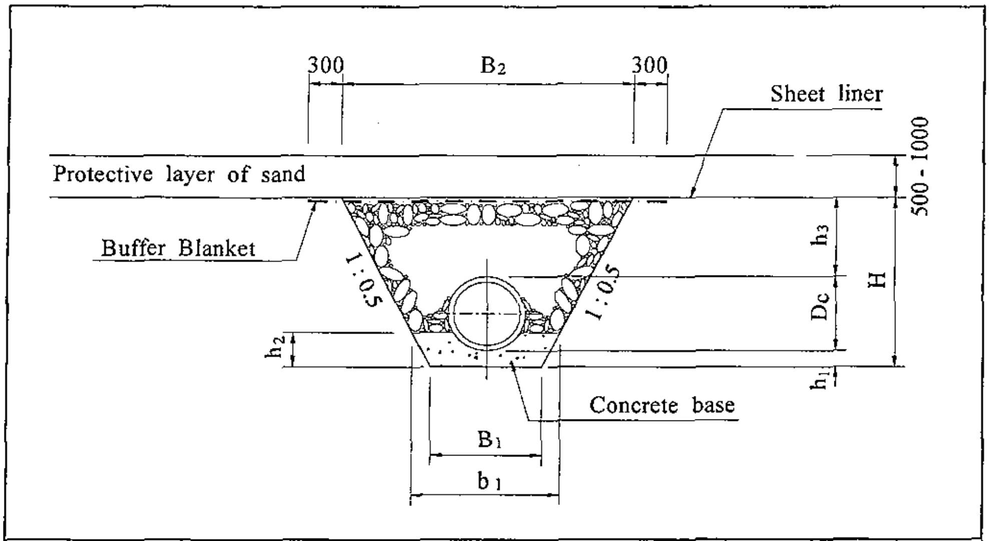
For the underground water drainage facility to function effectively, the desirable size and layout of the pipes and the suitability of filter materials to prevent clogging of pores on the pipes shall be selected carefully.

a) Cross-section Area

Generally, the required cross-section area for underground water drainage facility is determined empirically rather than strict calculation. Experiences have shown that pipes with diameter less than 10cm tend to get clogged up easily. The standard underground water and drainage pipe shall be between 15 to 30cm in diameter.

b) Interval

The spacing between underground pipes shall be determined depending on the site conditions such as topographical, geological and soil condition, area of coverage, etc. In general, a 20m interval is sufficient.



Ø	Type of pipe	T	Dc	B_1	B_2	H	b_1	h_1	h_2	h_3
1000	Perforated Hume pipe	82	1164	1500	3614	2114	1991	200	491	750
600	Perforated Hume pipe	50	700	1000	2600	1600	1325	150	325	750
300	Perforated Hume pipe	30	360	700	1960	1280	890	100	190	750

Dimensions (Unit : mm)

Figure II-15 Cross Section of Underground Water Drainage Facility

c) Filter material

Natural or graded gravels and stones of good permeability and aggregate distribution are recommended to be used as filter materials. The filter materials shall have grain with high stability, does not get eroded or melted and the grain size accumulative curve shall be appropriate.

The conditions which satisfy the situation where grains from surrounding area do not flow into the filter material is given by the following equation:

$$D_{15} \text{ (Filter Material)} / D_{85} \text{ (Surrounding Soil)} < 5$$

Where, D_{15} and D_{85} are the diameters of grain which passes the sieve to give a cumulative weight of 15% and 85% respectively of the total weight according to the grain size accumulative curve.

In addition, the condition where filter material has a relatively larger coefficient of permeability compared to the surrounding is given by the following equation:

$$D_{15} \text{ (Filter Material)} / D_{15} \text{ (Surrounding Soil)} > 5$$

In the case of perforated pipes, the grain size of filter material shall satisfy the following equation:

$$D_{85} \text{ (Filter Material)} / D \text{ (Diameter of Pore)} > 2$$

(4) Other Design Considerations

Besides the abovementioned, the following factors shall also be considered in designing of the of underground water drainage facility:

- A landfill site with an underground spring would require a large capacity underground water drainage facility. However, drainage pipes at 20 to 40m interval are recommended for all landfill sites as a measure of precaution.
- Spring water volume is depending on the factors such as topographical and geological conditions, rainfall volume, etc. In many cases, spring water volume fluctuations occur when surface liner facility is installed. Sometimes, the transformations of topography during construction causes fluctuation in spring water volume or its origin. Therefore, it is necessary to select countermeasures which are flexible enough to adopt any changes in site conditions.
- Underground water tends to concentrate at a particular spot depending on the topography of the landfill site. The construction plan shall be more flexible and taking considerations the unevenness and gradients of the landfill site location.
- The permissible uplift value varies with the type of liner facility. Subterranean drainage facility which is appropriate for the selected liner facility shall be installed when necessary.

Chapter 6 Gas Venting Facility

6.1 Necessity of Gas Venting Facility at Landfill Site

Various types of gases are generated by decomposition of organic materials in the landfill sites, which may cause fire disasters or affect the surrounding environment and human health. Therefore, it is necessary to carry out gas venting facility at landfill sites in order to prevent the adverse impacts caused by these gases. Besides, the gas venting facility also has an effect on accelerating the decomposition process of organic materials and promoting the stabilization of sanitary landfill site.

(1) Mechanisms and Impacts of Gas Generation

Organic substances in landfilled wastes generate various types of gases from the process of decomposition by micro-organisms. The decomposition process is generally divided into aerobic decomposition by the activities of micro-organisms that require oxygen and anaerobic decomposition by the activities of micro-organisms that do not require oxygen.

The decomposition processes are shown in chemical formulas as follows:

(Aerobic Decomposition)

$$(H_aO_bN_c + 1/4\ (4+a-2b-3c)O_2 \text{ --> } CO_2 + 1/2\ (a-3c)\ H_2O + cNH_3$$

(Anaerobic Decomposition)

$$(H_aO_bN_c + 1/4\ (4-a-2b+3c)H_2O \text{ --> } 1/8\ (4-a-2b+3c)\ CO_2 + 1/8\ (4+a-2b-3c)\ CH_4 + cNH_3$$

In anaerobic decomposition, methane (CH_4), carbon dioxide (CO_2), ammonia (NH_3) are generated as shown in the formula above with a very small amount of hydrogen sulphide (H_2S), methyl sulphide $(CH_3)_2S$, methyl mercaptan (CH_3SH).

It is necessary to treat the gas generated appropriately because it may cause adverse impacts such as withering of living trees, create obstructions to compaction, spreading of wastes and applying cover materials as well as causing fire and explosion.

For methane gas in particular, the concentration of approximately 5 to 15% may lead to explosion in landfill site (**Figure II-16**). As for hydrogen sulphide, it emits a foul odour over 3ppm concentration which may affect human health as shown in **Table II-12**.

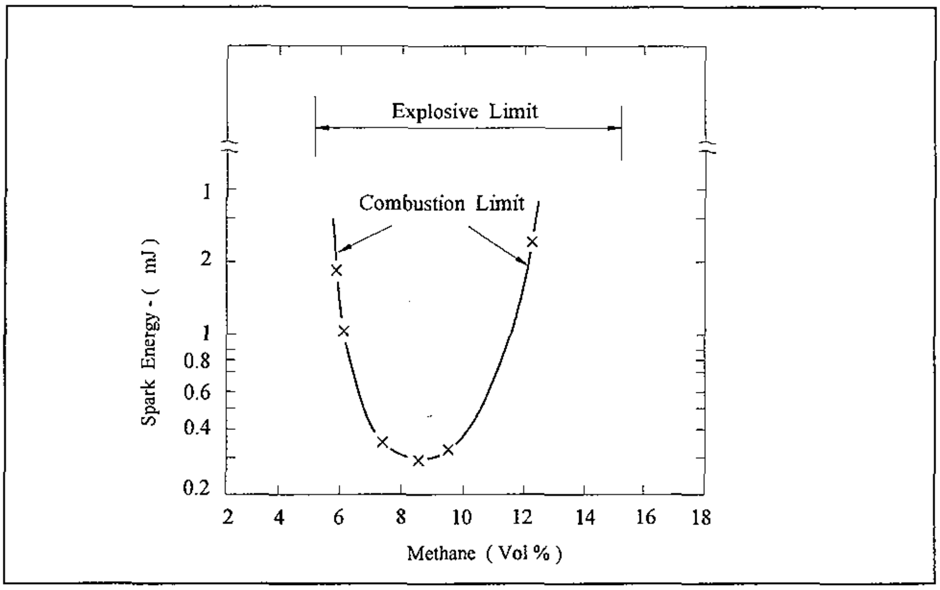


Figure II-16 Explosive and Combustion Limits of Methane Gas and Air Mixture at 20°C and Atmospheric Pressure

Table II-12 Influence of Hydrogen Sulphide to Human Body

H_2S Concentration (PPM)	Physiological Effect
1 - 2	A slight foul odour observed
2 - 4	A foul odour observed but not so painful
3	A foul odour remarkable
5 - 8	Analysts feel bad in the odour
80 - 120	Tolerable for 6 hours without any severe symptoms
200 - 300	Feel strong pain on mucus of eyes, nose and throat 3 to 5 min after smelling the odour and tolerable for 30 to 60 min with difficulty
500 - 700	Life is in peril with acute poisoning in 30 min inhalation.

(2) Fluctuation of Gas Generated

The changes in composition of gas generated show different tendencies depending on the conditions and thickness of the landfill layer, the quality and thickness of the cover soil as well as the type and size of landfill site. General pattern of gas generated from the landfill site is shown in **Figure II-17.**

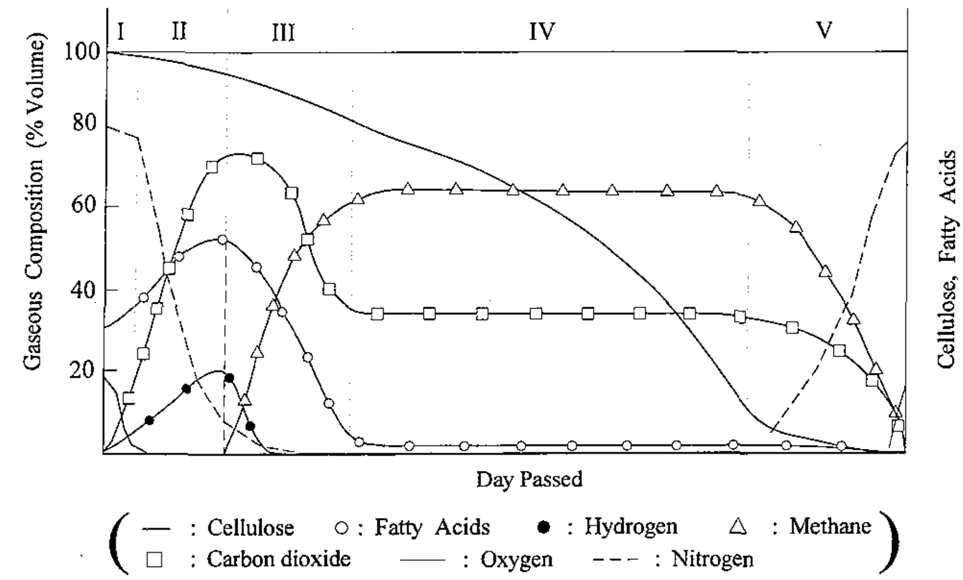


Figure II-17 Fluctuation of Gas Composition in Landfill By Time

6.2 Planning and Design Concepts

The main function of gas venting facility is to release the gases generated from the landfill layers as soon as possible before it creates environmental impacts on surrounding areas. It also indirectly accelerates the stabilization process of the landfill site. Gas venting facility needs to be planned and designed to suit these purposes. Since the gas generation continues during operation as well as after the landfill is completed, gas venting facility shall be designed with no impediments to the activities on the landfill site.

(1) Functions and Classification of Gas Vents

Gas venting facility functions mainly to remove the gas generated within the landfill layers into the atmosphere. Generally, it uses gas venting pipes (or gas vents) and in the case where the gas is aimed to be recovered for other purposes, appropriate gas treatment facility shall be considered.

Gas venting facility shall be constructed at the same pace as the landfilling works progress. Some classification of gas vents are described in **Figure II-18**.

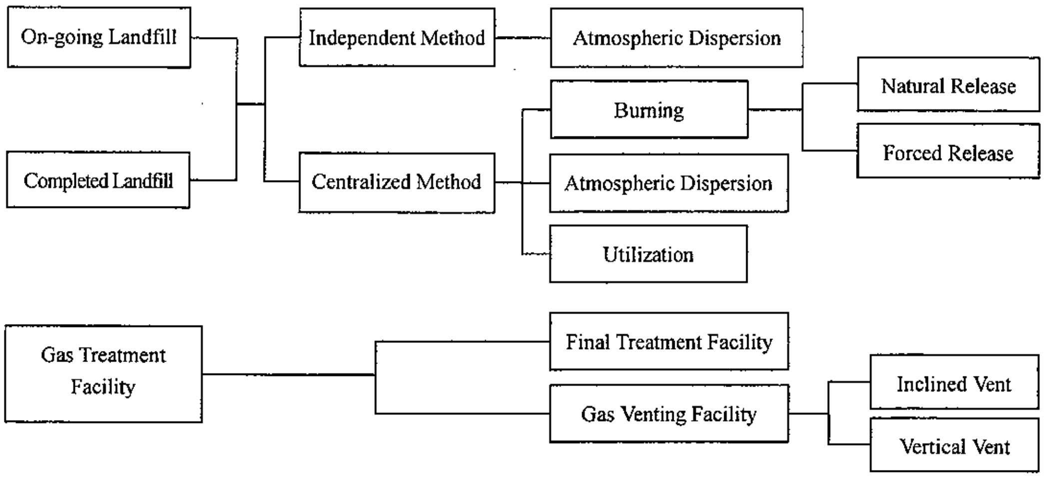


Figure II-18 Classification of Gas Venting Facility

Gas venting facility has the following effects, therefore the overall structure, position, size, etc. shall be taken into consideration when designing the facility.

- Expands aerobic zones within the landfill site and thereby helping enhance the waste decomposition processes.
- Since the aerobic zones are increased, inflammable gas and gas with bad odour components decreases, thereby it helps to improve the leachate quality.
- Water trapped within the landfill layers decreases and thereby it helps to stabilize the landfill layers.
- Easy management of the landfill site upon completion.

When establishing a gas venting facility, it is most important that the amount and composition of the gas generated be investigated. Sometimes gas venting pipes are also used as inclined pipes for leachate collection and discharge. Therefore, descriptions in Part II Section 2.4 of this guideline shall be referred when designing and planning gas venting facility.

(2) Design of Gas Vents in Operating Landfill Sites

The gas vents shall be built so as not to hinder the progress of the landfilling activities. Since most of the gas vents are progressively extended until the final height (height of the final cover soil layer) is reached, the gas is released into the atmosphere in most cases because the treatments by burning or other means are difficult.

Gas vents shall be constructed after giving due consideration to the gas flow. Generally the gas generated within the deeper layers of a landfill is not release into the atmosphere via the cover soil. In most cases, gas migrates along the slopes around the landfill site or along landfill layers (See **Figure II-19**). Thus the gas venting pipe positioned along the landfill slopes would be able to collect gases generated effectively.

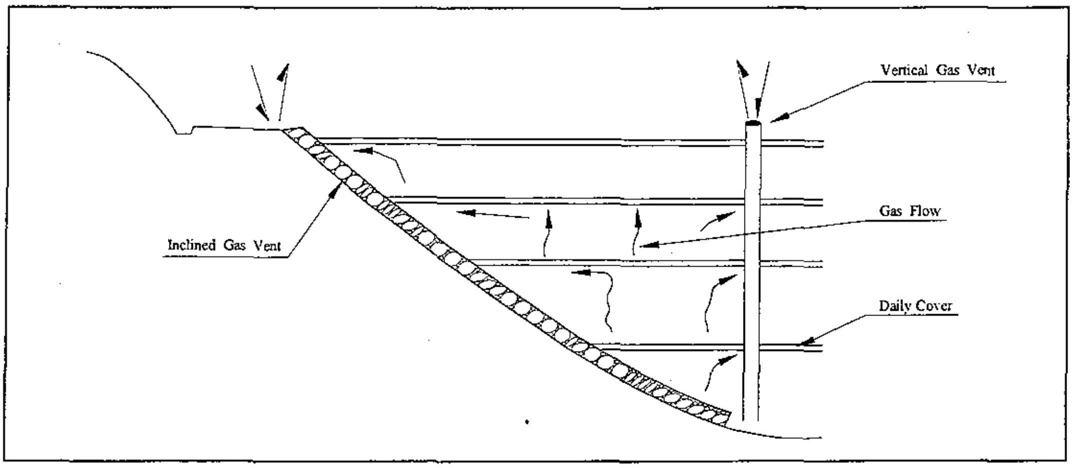


Figure II-19 Flow of Gas Produced in Landfill

a) Structure of Gas Vents

Gas venting facilities are usually in the form of a gabion or a combination of gabion with perforated PVC pipes. Most of the gabions are 300 - 500mm in diameter. On the other hand, vertical pipes are usually perforated PVC, porous Hume or steel pipes and the height will be extended as the landfilling progresses. Perforated PVC pipes are usually 150mm in diameter. Some examples of gas venting pipes are shown in **Figure II-20** and **Figure II-21.**

b) Intervals of Gas Vents

The intervals of gas venting pipes are depending on the amount of gas, flow of gas as well as the permeability coefficient within the landfill layers. The gas generation mechanism varies with the homogeneity of the landfilled wastes, waste decomposition rate, rainfall, temperature and other natural factors. Therefore, it is difficult to determine the exact interval for the gas pipes.

However, the intervals for gas vents can be determined theoretically. An example is shown in **Figure II-22.** This example shows the optimum interval of gas venting pipes built from the most bottom layer of an anaerobic landfill up to the cover soil as a function of landfill waste layer thickness, cover soil layer thickness and permeability coefficient of both layers.

The figure shows that the permeability coefficients of the final cover soil and the landfilled waste layer have a great influence on the intervals for gas venting pipes. At a landfill depth of about 10 to 20m, the gas venting pipe interval is about 20 to 60m, depending on the thickness of the final top soil.

In small scale landfill site with low daily landfilled waste volume, the gas venting pipes can be at short intervals of about 20 to 30m, while in large scale landfill site, the intervals for gas venting pipes shall be about 40 to 50m.

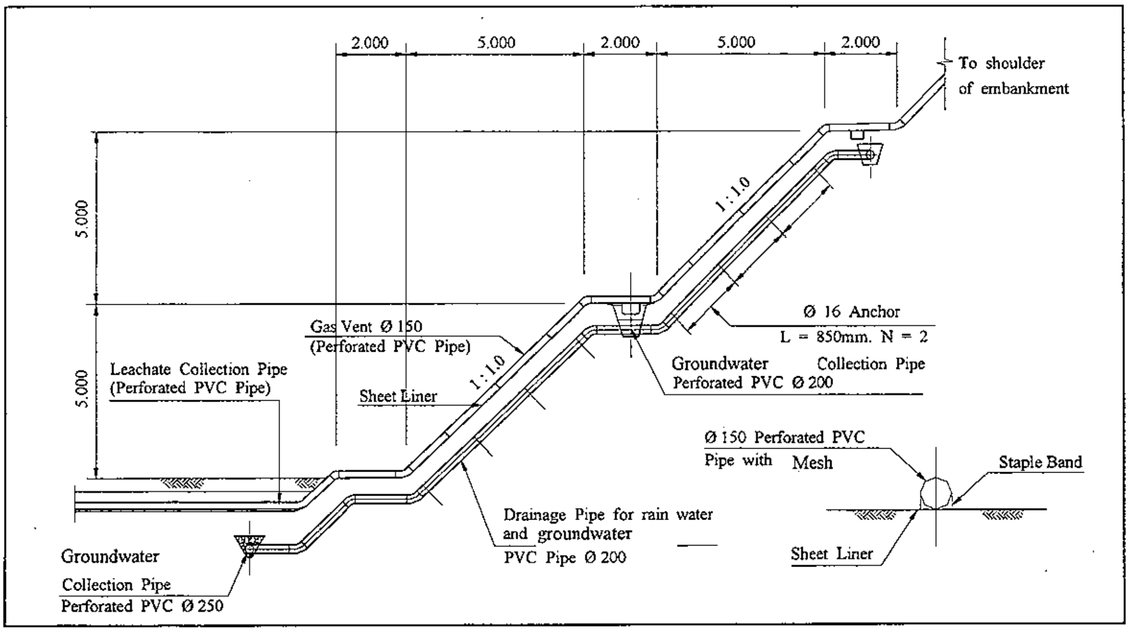


Figure II-20 Example of Vertical Gas Vent

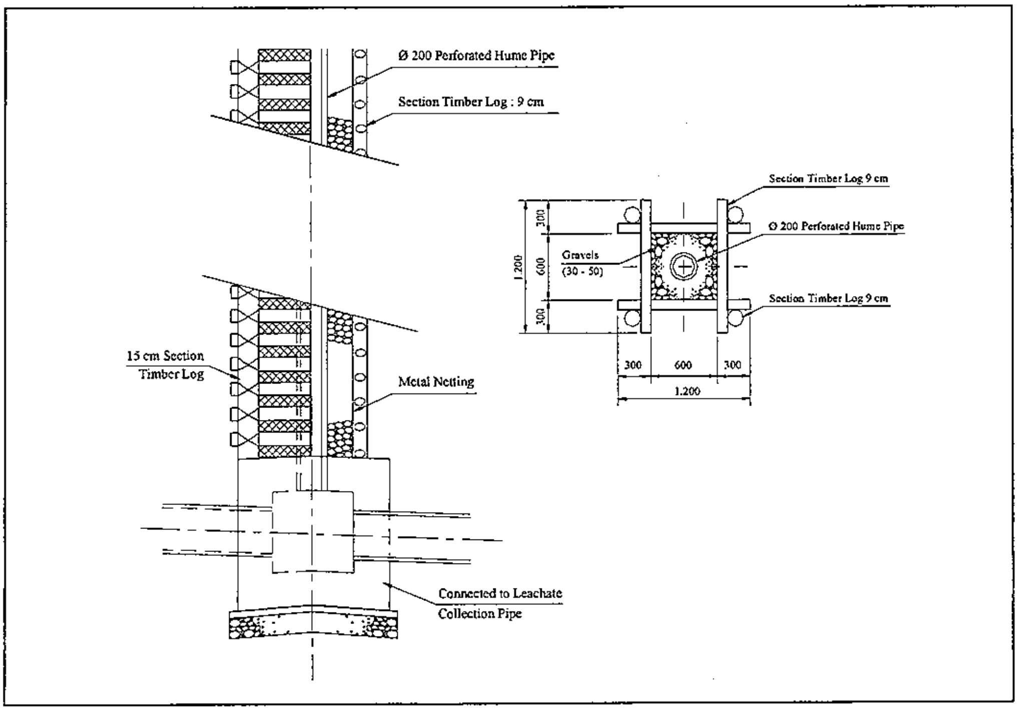
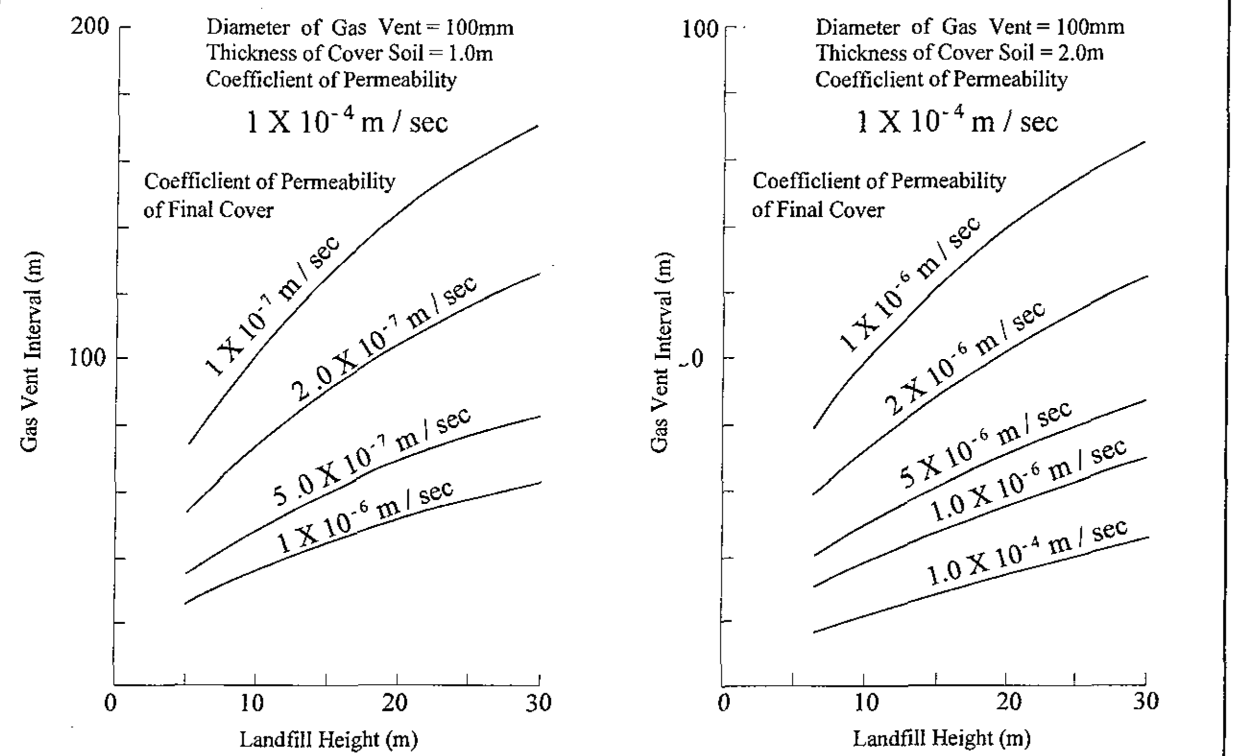
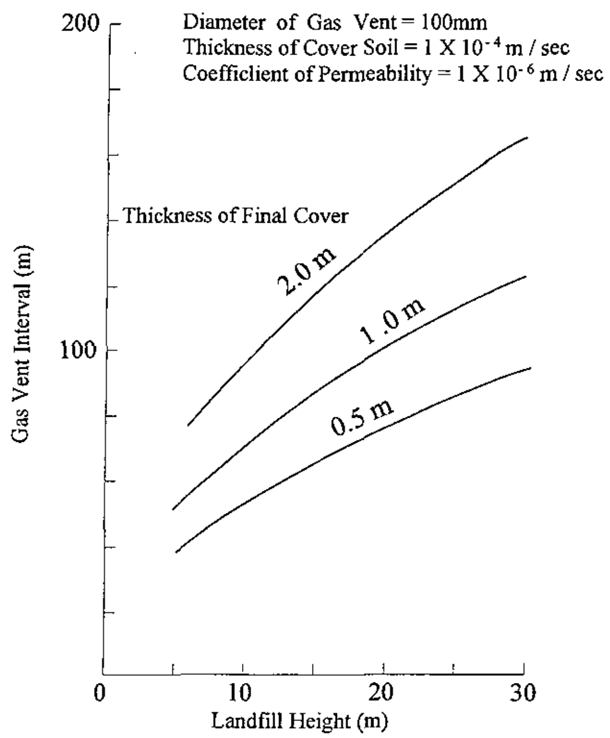


Figure II-21 Example of Inclined Gas Vent





The above calculations were made under the following condition :

(1) Gas Production = 10^{-4} m^3 / m^3_s
(2) Speed of gas emission is propotional to distance from the base of the landfilled waste
(3) Influence of on vent on the other is negligible
(4) Interval between two gas vents is calculated on the basis that all gas produced will be emitted

Figure II-22 Examples of Intervals for Gas Vents

(3) Design of Gas Vents in Completed Landfill Sites

The number of gas venting facility built on completed landfill site shall be as small as possible. There is still no established design method for the structure and layout of a gas venting facility for a completed landfill. Some existing examples of gas vents designed on completed landfill sites are shown in **Figures II-23, Figure II-24** and **Figure II-25.**

Figures II-23 and **Figure II-25** show examples of using vertical pipes to disperse the gas generated into the atmosphere.

Figure II-24 shows how gas collected by vertical gas venting pipes are passed in a horizontal direction in the crushed stone layer under the final cover soil. Here, the gas is mixed with that collected from the surrounding gas venting pipes positioned along the slope before being dispersed into the atmosphere. To prevent deterioration of the efficiency of gas collection due to settlement of the landfill or clogging of the gas pipes, the gas pipes shall be positioned along a slope of about 3%.

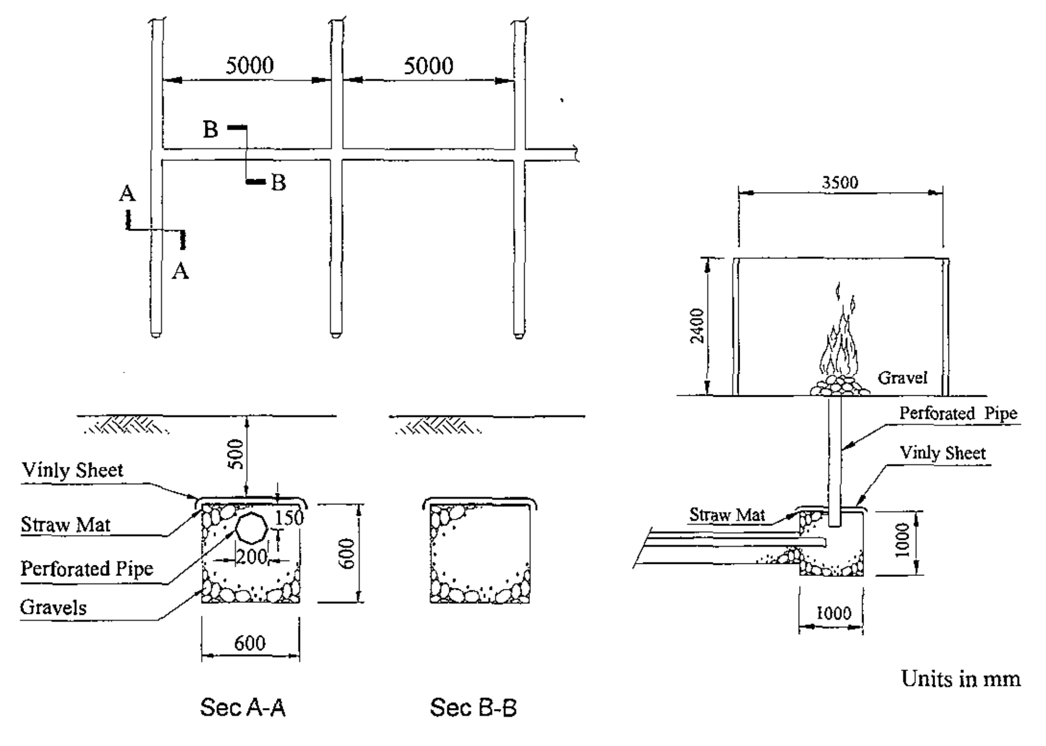


Figure II-23 Example of Gas Venting Facility

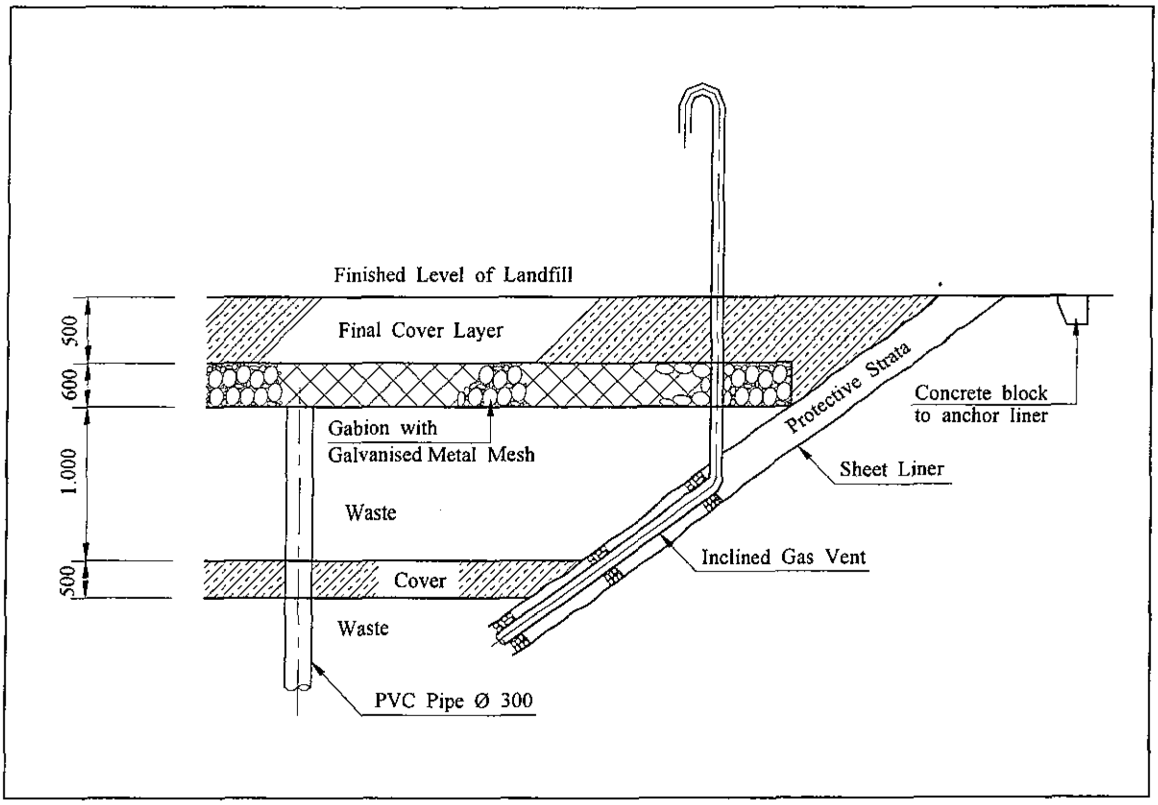


Figure II-24 Example of Gas Venting Facility

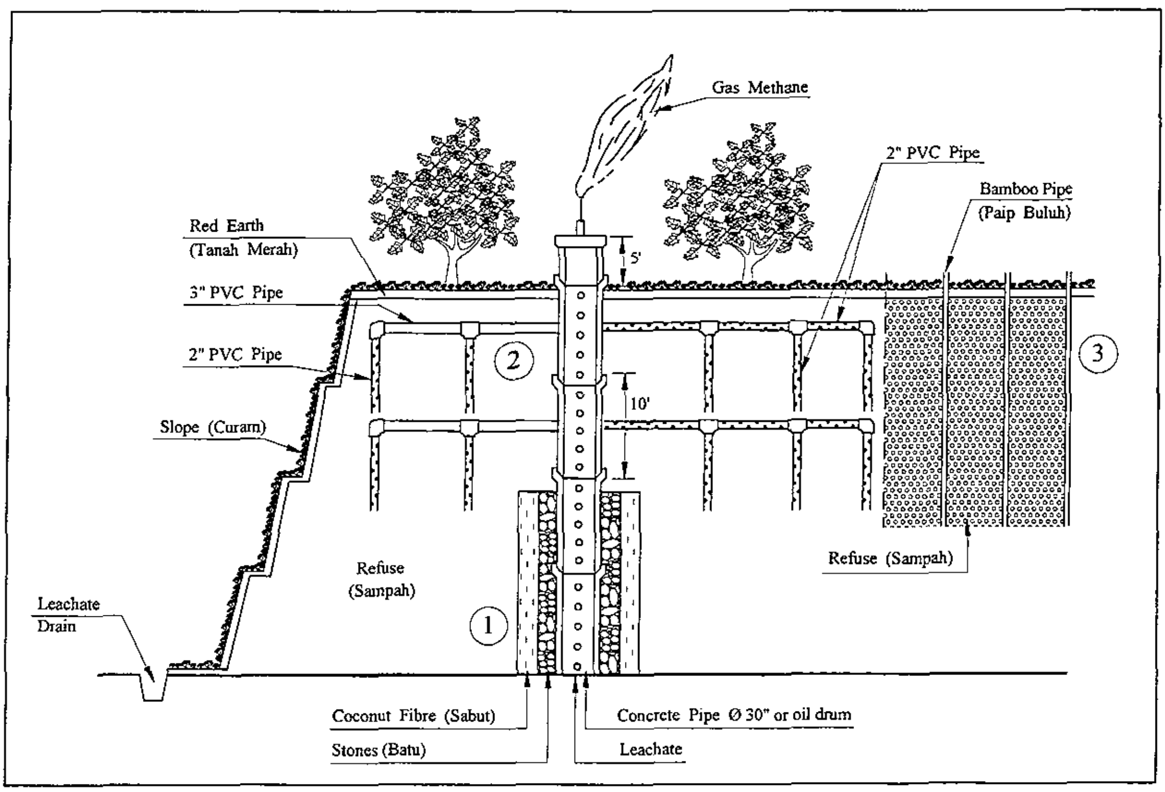


Figure II-25 Example of Gas Venting Facility

Chapter 7 Leachate Treatment Facility

7.1 General

7.1.1 Functions of Leachate Treatment Facility

The main function of leachate treatment facility at the landfill site is to purify the leachate collected so that the leachate will not pollute the surrounding water bodies or underground water when it is discharged into the environment.

It is important to note that leachate generation continues for a long period not only during the landfilling work, but also after the landfill completion. Since quantity and quality of leachate fluctuate depending on rainfall, waste composition, landfilling work etc., leachate treatment facility shall be planned and designed properly so that effective treatment can be achieved.

The following factors shall be considered for effective leachate treatment system.

(1) Selection of Leachate Treatment Process

A rational leachate treatment process shall be selected based on the requirement that the quality of leachate discharged is part of the conditions to be considered while designing the facility. Leachate quality is determined by the quality of landfilled waste, the landfill system, the landfilling methods etc. The quality of the discharged leachate shall comply with the Environmental Quality Act (1974).

(2) Countermeasures for Leachate Quality Fluctuations

The leachate is usually highly concentrated during the early stages of landfilling but as time passes, the concentration drops. Leachate at the early stages can be easily treated biologically but this becomes relatively difficult later on. Therefore, careful consideration such as the original typical leachate quality assumed for all stages of landfilling shall be given when selecting the leachate treatment method. Maintenance and operation measures become important at the later stages of landfilling. The biologically-difficult-to-treat leachate has to be reduced in volume or the system has to be switched over to physio-chemical treatment system.

(3) Countermeasures for Leachate Volume Fluctuations

Basically, volume of leachate changes with the amount of rainfall and there is usually a limit to the treatment capacity of the facility. Thus, in order to operate the facility effectively throughout the year, the leachate volume control is required. However, the cost effectiveness and feasibility of the leachate volume control and treatment facility may be questionable in areas with heavy rainfall since the capacity is depending largely on the adopted design of stormwater recurrence interval. Therefore, it is desirable to consider countermeasures to channel out rainwater or to prevent rainwater seepage into the landfilled waste layers by using section landfilling or separate landfilling as well as an appropriate selection of the cover soil materials so as to reduce the leachate volume as much as possible.

7.1.2 Planning and Designing Leachate Treatment Facility

When planning and designing the leachate treatment facility, it is necessary to understand the overall landfilling plan including the landfill scale and waste compositions. It is also important to investigate the overall rationality, consistency and effectiveness of the treatment facility.

The following factors shall be considered when planning and designing the leachate treatment facility.

(1) Scale of Leachate Treatment and Volume Control Facilities

The factors determining the scale of a treatment facility are such as the leachate volume and climatic conditions, especially the rainfall in the area. The most important factor to be considered in the design is the design of storm recurrence interval which is influenced by the landfilling stage, the local conditions etc.

In areas with seasonal leachate volume differences (for example, monsoon season or dry season), it is necessary to design the facility such that during peak volume season, multiple facilities can be operated in parallel while during low volume season, some of the facilities can be partially shut down. Preliminary observations on the flow volumes through hydrogeological surveys in a proposed landfill site shall be made when determining the size of the treatment facility. Water flow mechanism in the flow areas shall be analysed and understood. All these data can also be used in the design of liner facility or collection and discharge facilities for underground water.

(2) Designed and Treated Leachate Quality

In general, the designed leachate quality is determined by the quality of landfilled wastes. Therefore, before the design leachate quality can be established, the basic treatment plans, collection and transportation plans as well as the intermediate treatment plans shall be well understood. The landfilling method and type of landfill system shall be considered since the leachate quality changes with time depending on these factors.

The quality of the treated leachate is basically regulated under the maintenance and control standards of the Environmental Quality Act (1974).

(3) Leachate Treatment Method

Once the size of the leachate treatment facility, the designed leachate quality and the treated leachate quality are established, the treatment process shall be the next item to be considered. When planning the treatment process, the local conditions, maintenance and control of the treatment facilities based on fluctuations in the leachate volume, quality, land size, climatic conditions etc. have to be given careful considerations.

7.1.3 Components of Leachate Treatment System

Leachate treatment facility consists of leachate collection facility, leachate control facility, leachate transport facility, leachate treatment facility and leachate discharge facility. It is necessary to coordinate the planning and designing of the entire leachate treatment system in a sequence of leachate flow, collection, storage, treatment etc.

Besides leachate treatment facility, leachate collection facility, control facility, transport and discharge facility are some of the other parts that make up the overall leachate treatment system (refer **Figure II-26**).

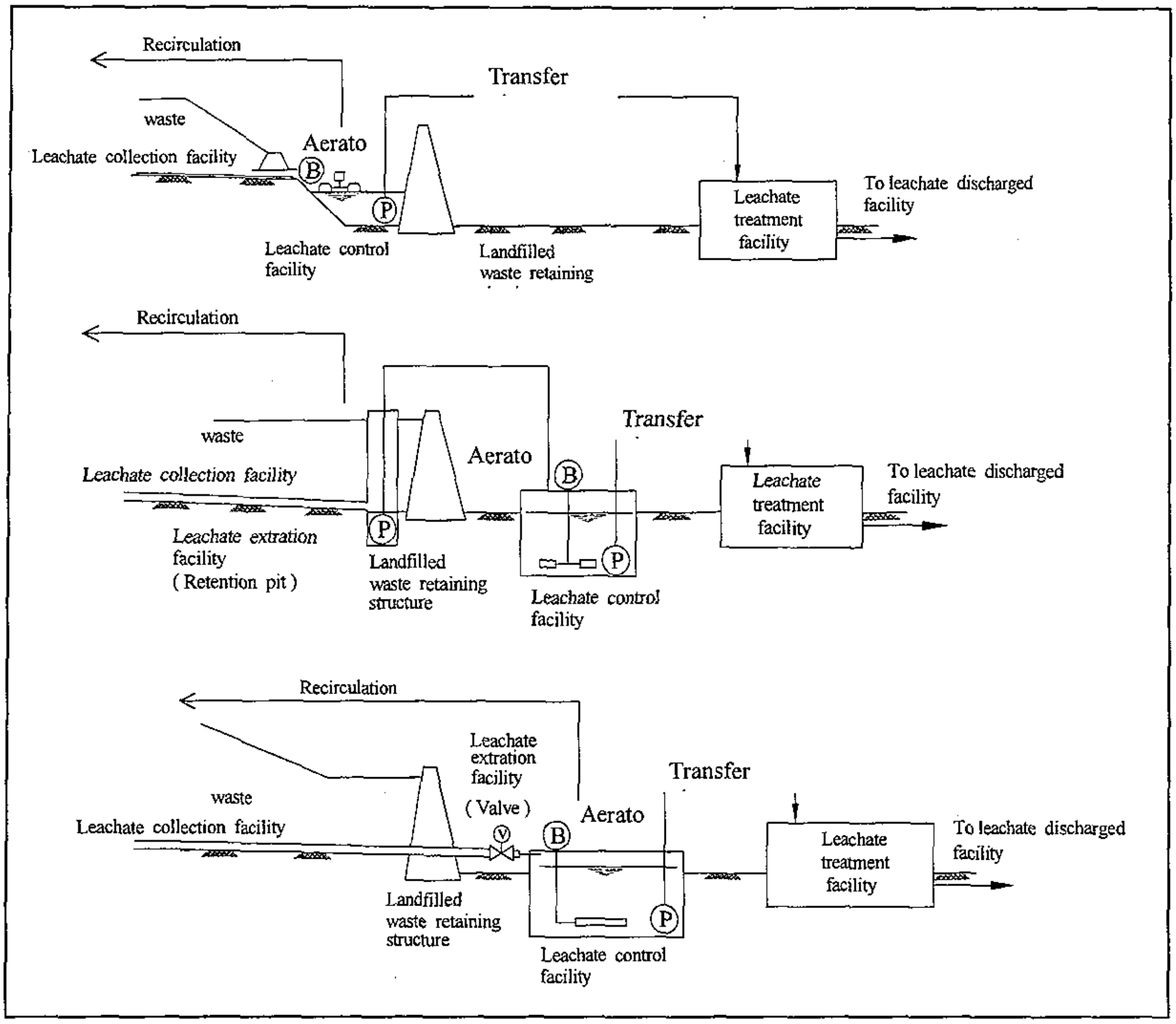


Figure II-26 Components of Leachate Treatment System

7.1.4 Concepts of the Operation and Maintenance

Operation and maintenance of leachate treatment facility shall be planned and designed appropriately so that it can perform its functions effectively.

The leachate treatment facility shall be carefully maintained and controlled.

(1) Control of Landfilled Waste

Since the landfilled wastes affect the quality of leachate, the conditions of the landfilled wastes shall be carefully controlled to observe any change occurring due to prevailing use of waste collection method, intermediate treatment process and landfilling operation etc.

(2) Observation on the Quality and Quantity of Designed and Treated Leachate

These data are important and necessary not only for the proper and cost effective management of the facility but also for the extension of existing facility as well as establishment of new facilities.

(3) Maintenance of Treatment Plant and Equipment

Treated leachate of a good quality can be only be achieved when the various components of the leachate treatment system are functioning properly. Therefore, daily inspection and maintenance of the treatment plant, equipment and chemicals etc. shall be carried out.

7.2 Design for Capacity of Leachate Controlling and Treatment Facilities

7.2.1 Leachate Control Facility/Leachate Retention Ditch

Capacity of leachate treatment facility shall be designed so that the facility is able to treat the generated leachate effectively. However, while the capacity of leachate treatment facility is designed and fixed, the leachate volume may fluctuate depending on the amount of rainfall. Therefore, it is necessary to design a comprehensive and rational capacity of leachate treatment system in conjunction with leachate control facility which mitigates the fluctuation of leachate volume.

When the capacity of a leachate treatment facility is designed and fixed, the volume of leachate is fluctuating mainly with the amount of rainfall. Therefore, it is necessary to design a comprehensive and rational capacity of leachate treatment system in conjunction with leachate control facility which mitigates the fluctuation of leachate volume.

An overflow control facility for stable operation of the leachate treatment facility or leachate retention ditch shall be constructed when necessary in order to ease the fluctuation of quantity and quality of leachate.

In order to offset sudden fluctuations in the leachate quality, the treatment facility shall also be equipped with pre-treatment functions such as pre-aeration.

In other words, a leachate control facility shall have the following capabilities:

- Measures to cope with sudden increases in leachate due to heavy rainfall
- Ensure a constant leachate quality
- Leachate storage ability during suspension of leachate treatment facility for repair and maintenance.
- Pre-treatment functions to prevent leachate putrefaction, sedimentation of suspended

solids etc.

Most of the leachate control facilities are in the form of dams, pond or retention ditch. Generally, the structures shall be strong enough to withstand the water pressures.

7.2.2 Design for Capacity of Leachate Control Facility

Capacity of leachate control facility must be designed properly in order to ease the fluctuation of quantity and quality of influent leachate, and perform stable leachate control.

(1) Basic Concepts

It is necessary to determine the capacity or other requirements of leachate treatment facility with a thorough understanding of the climatic conditions and actual conditions of the areas through comprehensive investigation.

Leachate volume fluctuates greatly, hence, in parallel with the reduction of the leachate volume by appropriate collection and control of stormwater, proper capacity design for leachate control facility which may decrease the loads to the leachate treatment facility is an important standpoint.

(2) Design Capacity for Leachate Control Facility and Design Flow of Leachate Treatment Facility

The design of inflow for leachate treatment facility between maximum and minimum values shall be determined. At the same time, the calculation procedure for determining the capacity of the leachate control facility to store the leachate exceeded the design capacity of leachate treatment facility shall be determined so that the system is able to treat the leachate generated day by day.

A series of flow of the calculation is shown in **Figure II-27.**

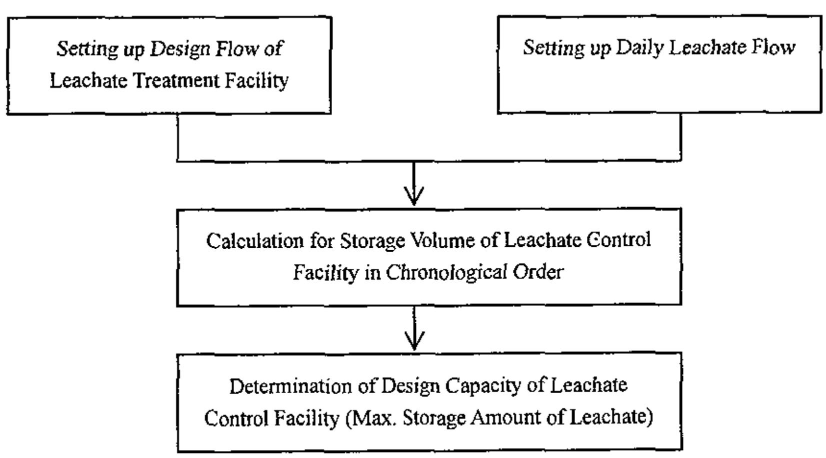


Figure II-27 Flowchart of Calculation Method for Capacity of Leachate Treatment Facility

7.2.3 Calculation of Leachate Generation

In order to design proper inflow or capacity of leachate control facility, understanding on the time sequence of daily leachate generation is crucial.

(1) Water Flow Balance Within a Landfill Site

The flow of water within a landfill site can be depicted as a water flow balance model in **Figure II-28** below.

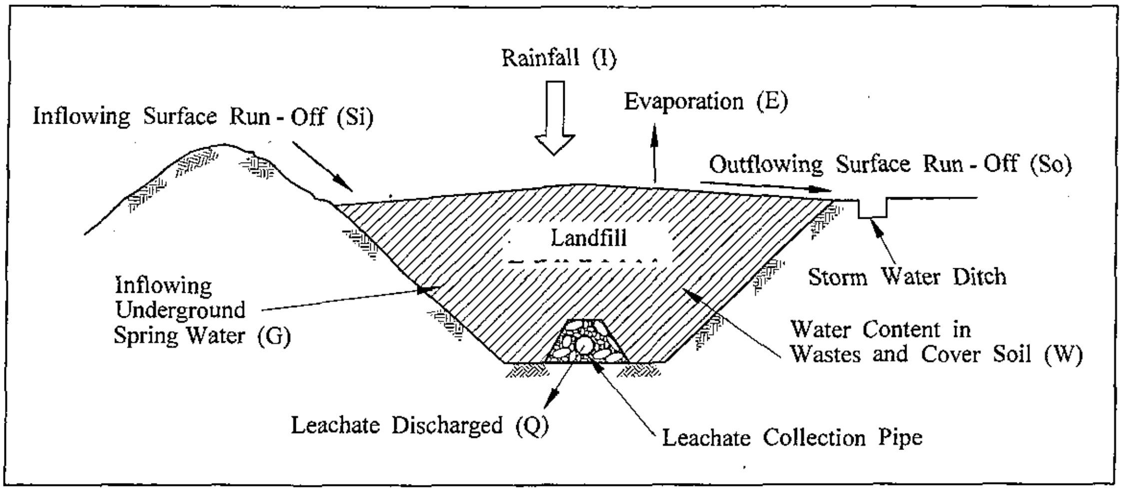


Figure II-28 Water Flows Balance Model for Landfill Site

From the figure, I is the rainfall intensity in mm. Water collection area A in m^2 multiplied by I gives the total volume of rainfall in m^3, therefore, total rainfall $m^3 = I \cdot A / 1000$.

E is the amount of evaporation in mm, and this shows the amount of moisture evaporated from the cover soil or the top waste layer by sunlight or wind. Si in m^3 expresses the water influx from outside of the landfill site by creeping along the land surface. This influx is usually stopped by stormwater collection facility. So in m^3, is the surface stormwater on the landfill site without seeping into the deeper layers. This is usually prevented by runoff collection drainage facility built when a phase of the landfill is completed. G is the underground water flow into the landfill site. It includes springs within the landfill site and is expressed in m^3. This water can be stopped by surface trenches. Q is the leachate volume in m^3. It is the influx collected or discharged by the leachate collection and discharge facility built within the landfill site. All the above values are calculated for a fixed time period t which is established according to the desired period for studying the water flow. W in m^3 is the moisture in the waste or cover soil transported into the landfill site during t.

Therefore, the water volume flowing within the landfill site in time t is calculated as follows:

Influx water volume $= I \cdot A / 1000 + Si + G + W$

Out flowing water volume $= E \cdot A / 1000 + So + Q$

Let the water moisture volume fluctuation in the cover soil be Cw while that in the waste be *Rw*, then the balance of water flow within the landfill site will be:

$$Si + G + W - (So + Q) + (I - E) \cdot A / 1000 = Cw + Rw \quad \text{..................(1)}$$

This is the fundamental equation for calculating the leachate volume within a landfill site.

When surface trenches exist, $G = 0$, and if surface water influx is removed by stormwater drains, then $Si = 0$. If W is so small that it can be ignored, and t is so long that Cw and Rw becomes negligible, then the following equation can be assumed,

$$(I - E) \cdot A / 1000 - So = Q \quad \text{..................(2)}$$

(2) Computation of Daily Leachate Volume By Time Series

Although the exact leachate volume generated can be calculated from equation (1), there are too many parameters that control evaporation and surface outflow and thus this calculation method is not satisfactory. Therefore, daily leachate volume generated are usually determined by either the method using an approximate water inflowing and out flowing (water balance) model or the method based on actual observations.

Once the values for daily rainfall, evaporation and surface outflow are obtained, an approximate leachate volume generated daily can be calculated from equation (2).

a) Water Balance Model Method

There are 2 methods, one is using a rational equation based on equation (1) and the other considers the time lag between the time of water influx due to rain and the time of leachate generation. The former is described below while the latter is described in the Appendix.

The method by rational equation was originally used for determining the surface runoff from the relationship between rainfall intensity and outflow volume. This method is appropriate for calculating the leachate volume within a landfill site.

In general, the volume of leachate generated is calculated as follows:

$$Q = (C / 1000) \cdot I \cdot A \quad \text{..................(3)}$$

Where,

Q	:	Leachate volume (m^3/day)
I	:	Rainfall intensity (mm/day)
C	:	Leachate coefficient
A	:	Landfill area (m^2)

The leachate coefficient C is greatly influenced by the land surface conditions. It is different when, for example, the landfill section is being worked or in the case when the final cover soil has been laid and the surface stormwater completely dispelled from the completed section. Let the former coefficient be C_1 and the latter be C_2, their respective leachate volumes generated be Q_1 and Q_2 , the area of section being landfilled be A_1 and that of the completed section be A_2. Equation (3) then becomes

$$Q = Q_1 + Q_2 = (1 / 1000) \cdot I \cdot (C_1 \cdot A_1 + C_2 \cdot A_2) \quad \text{..................(4)}$$

The rain fallen in un-worked landfill section is assumed to flow completely out of the landfill site. Thus, in equation (4), replace I with the daily rainfall time series I_j (j = 1~365), then Q_j, the daily leachate volume time series can be determined. C_1 and C_2 are computed as described below. A_1 and A_2 changes with the progress of landfilling but the design requires that the A_1 and A_2 combination used shall produce a larger water volume than actual case. I_j depends on actual conditions but the main assumption is that the leachate is stored in the control facility. Assume that the landfill site is used for 10 years, the once in 10 years rainfall probability will give the daily rainfall by time series.

i) Computation of C_1

When the surface stormwater is not expelled from a section being landfilled, then from equation (2),

$$Q_1 = (I - E_1) \cdot A_1 / 1000 \quad \text{......} \quad (5)$$

Equation (3) becomes

$$Q_1 = (C_1 / 1000) \cdot I \cdot A_1 \quad \text{......} \quad (5a)$$

From equations (5) and (5a),

$$C_1 = 1 - (E_1 / I) \quad \text{......} \quad (6)$$

ii) Computation of C_2

Since the surface stormwater is completely removed from the completed section, equation (2) remains as it is,

$$(I - E_2) \cdot A_2 / 1000 - So = Q_2 \quad \text{......} \quad (7)$$

But equation (3) becomes

$$Q_2 = (C_2 / 1000) \cdot I \cdot A_2 \quad \text{......} \quad (7a)$$

From equation (7) and (7a),

$$C_2 = 1 - \{(E_2 + 1000 \cdot So / A_2) / I\} \quad \text{......} \quad (8)$$

From equations (6) and (8),

$$C_2 = C_1 \cdot [1 - \{(E_2 - E1 + 1000 \cdot So / A_2) / (I - E_1)\}]$$

$E_2 - E_1$ is negligible when compared with $1000 - So / A_2$

$$C_2 = C_1 \cdot [1 - \{(1000 \cdot So / A_2) / (I - E_1)\}] \quad \text{......} \quad (9)$$

In equation (9), $[1000 \cdot So / A_2 / (I - E_1)]$ depends on the soil quality or the gradient of the final cover. But in general, surface stormwater can be removed because the cover material is impermeable to water, the surface is compacted and has a slope formation. Actual observations have set that value to be equal to 0.4 assuming a low population density of plants. Thus,

$$C_2 = C_1 \cdot (1 - 0.4) = 0.6\, C_1 \quad \text{......} \quad (10)$$

b) Method by Actual Observations

A test area shall be established in the same landfill site. Based on the measured values for the leachate volume in this area or an area under the same landfill conditions, the leachate volume in the landfill area can be estimated empirically.

Let the area of test landfill section be A_1', the area already landfilled be A_2', their respective leachate coefficients be C_1', and C_2', leachate volume be Q', rainfall intensity be I then equation (4) for the test landfill section will become

$$Q' = (1/1000) \cdot I \cdot (C_1' \cdot A_1' + C_2' \cdot A_2') \quad \text{.............................(11)}$$

On the other hand, if the actual area of on-going landfill section is A_1, the completed landfill section A_2, their respective leachate coefficients C_1' and C_2', leachate volume Q' and the rainfall intensity I, then equation (4) becomes

$$Q = (1/1000) \cdot I \cdot (C_1 \cdot A_1 + C_2 \cdot A_2) \quad \text{.................................(12)}$$

Since the waste quality and surface conditions are similar in these 2 areas, $C_1 = C_1'$ and $C_2 = C_2'$. Also $C_2 / C_1 = \alpha$ (where $\alpha = 0.6$), then equations (11) and (12) become

$$Q = Q' \cdot \{(A_1 + \alpha A_2) / (A_1' + \alpha A_2')\} \quad \text{................................(13)}$$

Since Q', A_1' and A_2' are observed values in the test area, equation (13) gives the leachate volume in an actual landfill site.

(3) Designed Leachate Volume

a) Concept of Designed Leachate Inflow

This value shall be established when planning a leachate treatment plant. Although the daily leachate volume can be determined in the methods mentioned previously, it varies with time. As long as the fluctuations are within the capacity of the leachate control facility, the overflow can somehow be regulated. Even then only if the capacity were made infinitely large, the average of the annual leachate values can be assumed to equal the design leachate volume. Therefore, in general the design leachate volume is determined from considerations made on the average leachate volume, maximum leachate volume and the capacity of the leachate control facility. It is extremely difficult to work out the average or the maximum leachate volume from the predicted daily leachate volume for the whole operation period of the facility. Calculation data are enormous and unrealistic. Therefore, average and maximum leachate volume is usually obtained in the following manner. The design leachate volume is then set at a value in between that of the average and the maximum leachate volume with due considerations given to measures to control the leachate.

b) Calculation of Average and Maximum Leachate Volume by Rational Equation Method

The general equation of determining the volume of leachate generated is given by

$$Q = (C / 1000) \cdot I \cdot A$$

Where,

Q	:	Leachate volume (m^3day)
C	:	Leachate coefficient
I	:	Rainfall intensity (mm/day)
A	:	Landfill area (m^2)

Therefore,

$$Q = (1/1000) \cdot I \cdot (C_1 \cdot A_1 + C_2 \cdot A_2),$$

where A_1 and A_2 are the values obtained from on-going and completed sectioned landfilling. The maximum leachate volume obtained for various combinations of A_1 and A_2 will give the design leachate volume.

The annual average daily rainfall (mm/day) is considered when calculating the average leachate volume, similar with the monthly average daily rainfall (mm/day) calculated from the month with highest rainfall for the year is used to obtain the maximum leachate volume. Rainfall data shall be obtained from a meteorological station located near the landfill site or those data collected continuously for more than 20 years. If such data are not available, then observations before implementation are necessary. Checked and compared with data from the nearest weather station.

The reason for using long-term weather data for the rainfall is because fluctuations in the leachate volume are regulated by the leachate control facility. Instead of letting the leachate treatment facility bear the overflow load, it would be more efficient and cost effective to let the leachate control facility bear the load.

Examples of actual calculation by using this method are shown in Appendix 3.

7.3 Design for Raw and Treated Leachate Quality

For designing leachate treatment facility, it is necessary to design proper system in order to achieve desirable water quality of raw and treated leachate.

7.3.1 Design for Raw Leachate Quality

Design for raw leachate quality is determined by considering cases of water quality analysis at other sanitary landfills that are having relatively similar waste compositions and the landfill structure.

In general, the level of pollution of the raw leachate is high. For example, the level of organic contents in the raw leachate during the early stages of landfill is high. As time passes, the pollution level drops and after several years, only the non-biodegradable substances are left. The leachate quality is generally determined by the quality of landfilled wastes but there are also effects from the type of landfill system, landfilling method, size, time etc. Therefore, it is desirable to set the design leachate quality based on the results of leachate quality observed at other landfill sites which have comparatively similar waste compositions or landfill type.

(1) Treatment Order of Leachate

The parameters of leachate quality to be analysed are determined by the Environmental Quality Regulation (1978), as well as the landfilled waste compositions, the water usage in the surrounding areas etc. Therefore, the intermediate waste treatment methods shall be understood, the landfilled waste compositions shall be investigated and at the same time, the water usage such as water supply, irrigation, industrial water supply, etc. shall be determined.

A categorization of treatment orders from the viewpoint of leachate treatment facility planning is shown in **Table II-13**.

Table II-13 Leachate Parameters for Planning a Leachate Treatment Facility

	Evaluation During Planning of Treatment Facility	Parameters
A	Necessary when setting the design raw leachate quality level based on design condition required of the discharged water which in turn will determine the type of treatment method and size of facility	BOD, SS, COD, Ca^{2+}, NH_4^+-N, T-N
B	Design of facility is standard once the necessity of treatment is identified	pH, E-Coli
C	No need to consider when setting the design raw leachate quality because these parameters will be removed during the process of treating other components	Fe^{2+}, Mn^{2+}, Other heavy Metal; Colour and Odour
D	There is no existing commercial way to treat these parameters. Only option available is to decide the suitable location to dispose of them	TDS, Cl^-, etc.

(2) Factors Affecting Leachate Quality

Leachate quality is affected by waste compositions, the landfill age, the type of landfill system as well as the landfilling method.

Figures II-29 and **Figure II-30** show the fluctuations of leachate quality depending on different types of landfill system. The data are collected from 3 places of sanitary landfill system over a period of 10 years after commencement of actual landfilling. From these data, it is obvious that BOD concentration peaked (1,000 mg/L) at all A, B and C immediately after commencement of landfilling. After 1 year of landfilling under the semi-aerobic landfill system, the BOD concentration drops to below 100 mg/L. But in the case of improved anaerobic sanitary landfill system, the BOD concentration drops first and then rises again and it requires about 3 years after completion of landfilling in order for it to drop to below 100 mg/L.

NH_4^+-N concentration peaks a little later than BOD levels. In the case of combustible wastes, the peak would be 3 years after commencement of landfilling and it will drop in a more gradual manner as compared with BOD.

Therefore, the stabilization of leachate quality in a landfill site under the semi-aerobic or the aerobic landfill systems is relatively faster and the concentrations of parameters drop faster.

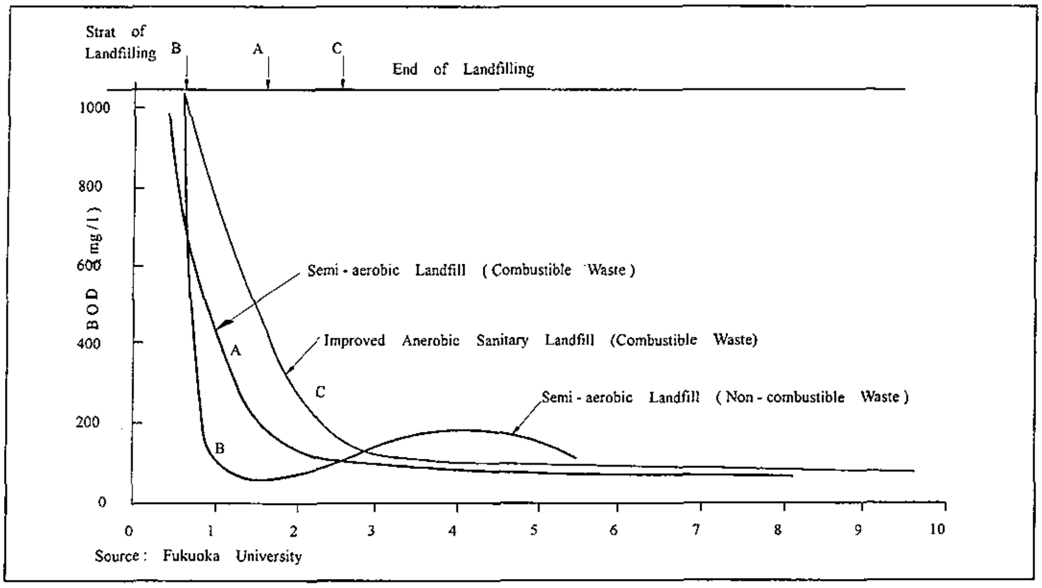


Figure II-29 Fluctuation of BOD According to Different Types of Landfill System

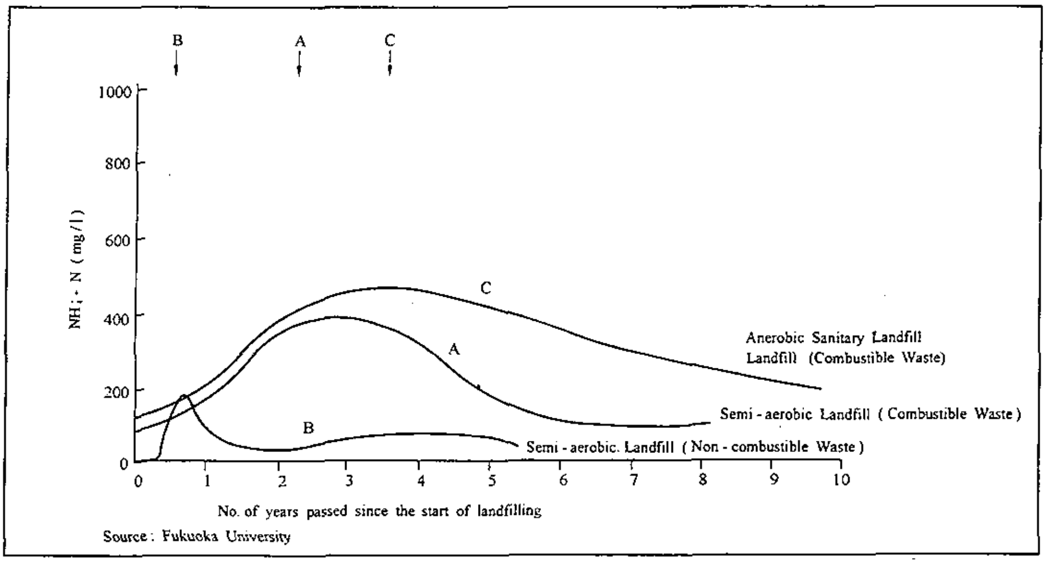


Figure II-30 Fluctuation of NH_4^+-N According to Different Types of Landfill System

(3) Fluctuations of Leachate Quality

Leachate quality changes as time passes with the decomposition and stabilization of the landfilled wastes. For example, the levels of BOD, COD, NH_4^+-N concentrations change with time as shown in **Figure II-31.** In general, low design loads (volume x quality) of leachate treatment plants are comparatively easy to cope with but large loads are difficult to handle once a certain limit is exceeded. When the fluctuations in leachate quality are too high, management of the operation of the facility becomes difficult. Therefore, the following factors shall be considered before deciding on the leachate quality or load volume during the initial stage of landfilling:

- homogenisation possibility by leachate control facility,

- the volume and quality peaks do not necessarily match and
- capability to cope with load fluctuations.

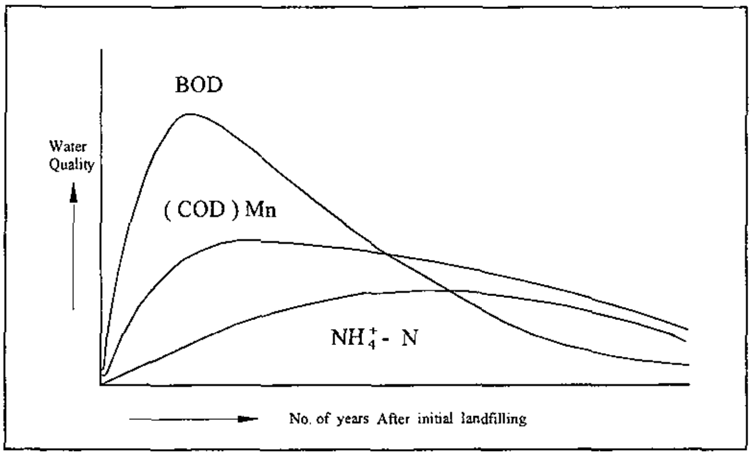


Figure II-31 Fluctuation of BOD, COD and NH_4^+-N, (Calculation Model)

<Measuring method of COD>
COD (Chemical Oxygen Demand) is a water quality index indicating the amount of organic matters.
In measurement of COD, sample water is analysed by adding an oxidizer under certain conditions first, then the quantity of the oxidizer consumed is calculated, and COD is calculated by converting it into the quantity of corresponding oxygen.
For a measuring method of COD, the" $KMnO_4$ method" which use $KMnO_4$ as the oxidizer and the "$K_2Cr_2O_7$ method" which use $K_2Cr_2O_7$ as the oxidizer are widely used and they are called COD_{Mn} and COD_{Cr} respecticvely.
Although it has low oxidation ratio, "$KMnO_4$ method" is simple and widely used as a measure of relative comparison of the amount of organic matter contents. The $K_2Cr_2O_7$ method has the feature that the oxidation ratio is high. In case of making COD into the index indicating the total quantity of organic matter contents measuring the organic matter which exists in suspended solids, $K_2Cr_2O_7$ method is suitable. Therefore, a value of COD_{Cr} tends to become larger than that of COD_{Mn}.
As the analytical method of COD, $K_2Cr_2O_7$ method is generally used across the world. However in Japan and Britain, $KMnO_4$ method is adopted as standard since $KMnO_4$ method may generate wastewater which contains large quantity of mercury and silver. Therefore, in this document, "COD_{Mn}" is used for COD.

(4) Determination of Raw Leachate Quality

Basically, the raw leachate quality is determined by the waste compositions as well as the type of landfill system, method, catchments area etc. However, the quantitative relationships are not. Therefore, the estimated leachate quality is basically determined by comparing the leachate quality observed in other landfill sites with similar waste composition and landfill system.

a) Examples of Raw Leachate Quality

Table II-14 shows an example of the design leachate quality depending on the type of landfill wastes.

Table II-14 Variation of Raw Leachate Quality with Different Waste Types (Survey of 59 Locations in Japan)

	Combustible Waste	Non- combustible Waste	Mixed Waste
pH	5.0 ~ 8. 6	4.0 ~ 9.0	4.0 ~ 8.6
BOD (mg/L)	250 ~ 2500 (1000)	10 ~ 2200 (500)	500 ~ 1000 (500)
COD_{Mn} (mg/L)	200 ~ 800 (400)	20 ~ 3600 (400)	450 ~ 500 (450)
SS (mg/L)	100 ~ 500 (200)	80 ~ 3200 (200)	150 ~ 500 (400)
NH_4^+-N (mg/L)	200 ~ 400 (200)	42 ~ 400 (200)	250 (250)

Note : ( ) medium value
COD using $KMnO_4$ Method

b) Estimated Leachate Quality Standard

Table II-15 shows some standards for setting the leachate quality.

Table II-15 Guidelines for Raw Leachate Quality in Semi-Aerobic Landfill Type

Item	Combustible Waste	Non-combustible Waste or Incineration Residue	Remark
BOD	1,200 mg/L	250 mg/L	1) Landfill Type : Semi-aerobic Type 2) Operation Period : 5 years Landfill Height : 4m 3) Ignition loss of ash : 8% 4) For TDS, the presence or absence of HCl and dust removal facility at the incinerator shall be considered 5) If dust is also buried, besides TDS, the amount of Ca^{2+} and other heavy metals shall be checked . 6) COD using $K_2Cr_2O_7$ Method
SS	300 mg/L	300 mg/L	
COD	1,500 mg/L	300 mg/L	
NH_4^+-N (T-N)	500 mg/L	100 mg/L	
pH	Acidic if amount of decomposed organic waste is high	Alkaline if amount of ignition loss in ash is low	
TDS	Around 10^3 ~10^4 mg/L		
E-Coli	May exceed amount of 3,000		
Fe^{2+} , Mn^{2+} Other Heavy Metals	Fe^{2+} : Trace amount Mn^{2+} : Trace amount Others : Not detected		
Colour	Dark brown to light yellow		

7.3.2 Design for Treated Leachate Quality

It is necessary to observe the treated leachate quality so that it is complied with the standards regulated by law.

The Third Schedule of the Environment Quality Act (1974) which stipulates regulations on environment quality of sewage and industrial effluents enforced by the DOE since 1978 is listed in **Table II-16** below.

Table II-16 Third Schedule of Environment Quality Act (1974)

Third Schedule
Environmental Quality Act 1974
Environmental Quality (Sewage and Industrial Effluents)
Regulations 1978

[Regulations 8(1), 8(2), 8(33)]
Parameter Limits of Effluent of Standards A and B

	Parameter	Unit	Standard	
			A	B
(i)	Temperature	°C	40	40
(ii)	pH Value	-	6.0 - 9.0	5.5 - 9.0
(iii)	BOD5 at 20 °C	mg/L	20	50
(iv)	COD	mg/L	50	100
(v)	Suspended Solids	mg/L	50	100
(vi)	Mercury	mg/L	0.005	0.05
(vii)	Cadmium	mg/L	0.01	0.02
(viii)	Chromium, Hexavalent	mg/L	0.05	0.05
(ix)	Arsenic	mg/L	0.05	0.10
(x)	Cyanide	mg/L	0.05	0.10
(xi)	Lead	mg/L	0.10	0.5
(xii)	Chromium, Trivalent	mg/L	0.20	1.0
(xiii)	Copper	mg/L	0.20	1.0
(xiv)	Manganese	mg/L	0.20	1.0
(xv)	Nickel	mg/L	0.20	1.0
(xvi)	Tin	mg/L	0.20	1.0
(xvii)	Zinc	mg/L	1.0	1.0
(xviii)	Boron	mg/L	1.0	4.0
(xix)	Iron (Fe)	mg/L	1.0	5.0
(xx)	Phenol	mg/L	0.001	1.0
(xxi)	Free Chlorine	mg/L	1.0	2.0
(xxii)	Sulphide	mg/L	0.50	0.50
(xxiii)	Oil and Grease	mg/L	Not Detectable	10.0

Note: COD using $K_2Cr_2O_7$ Method

7.4 Methods for Leachate Treatment

Leachate treatment facility shall be designed in a way that it is able to perform consistent treatment of leachate and make the facility rational in terms of its operation and maintenance as well as economical standpoints.

7.4.1 Basic Concept

Among many leachate treatment methods such as preliminary treatment and control of leachate, recirculation, biological treatment, and natural attenuation etc, it is necessary to adopt the most rational and economical combination, which is able to comply with the effluent standards established by Department of Environment, Malaysia.

Design for leachate treatment is determined by the raw leachate quality, target parameters to be treated as well as the degree of treatment required in order to comply with the effluent standards established by DOE.

Leachate treatment consists of several processes. Each treatment process has different initial cost or operation and maintenance cost. Besides, labour for operation and maintenance as well as areas required for treatment facility are also different. Hence, optimum combination of the treatment processes adapted to conditions of each landfill site shall be selected.

Leachate water quality is decided by the quality of the landfilled waste. The relation between the kind of landfilled wastes and the water quality items used as the main targets of leachate treatment process is shown in **Table II-17**.

Table II-17 Relation between Landfilled Wastes and Targets of Leachate Treatment

Kind of Landfilled Wastes	Targets of Leachate Treatment
Organic-rich Waste (Mixed Waste, Combustible Waste)	high-BOD, COD, NH_4^+-N, Fe_2^+, Mn_2^+, Colour, Odor
Non-Combustible Waste	low-BOD, COD, NH_4^+-N
Ash, Dust	Ca^{2+}, low-BOD, COD, NH_4^+-N, Heavy Metals

In cases where the landfilled wastes are mainly combustible materials, biological treatment will be the main process of treatment flow. On the other hand, when incinerated residues or incombustible materials are the main portion of the landfilled wastes, physio-chemical treatment becomes the main process. Main treatment method to be implemented differs depending on the progress of landfilling. Biological treatment is dominant at the early stage of landfilling. However, at the later stage, physio-chemical treatment becomes the principal method through a series of flow.

When introducing the incineration system as the intermediate treatment, the quality of the landfilled waste becomes inorganic-rich wastes like ash and dust. By the incineration process, the inorganic matters such as salt and calcium and so on are concentrated in the incineration residue. The inorganic matters such as heavy metals tend to exist in the incineration residue as compounds such as oxide and chloride through the high temperature reaction, and become easy to dissolve. The potential of heavy metal pollution which is caused by the landfilled waste becomes higher. Therefore, when landfilling the incineration residue, it is necessary to introduce a physio-chemical treatment from the viewpoint of the measure against toxic substance, and it is necessary to implement a measure against calcium scale as the preprocessing.

Since quantity and quality of leachate may fluctuate in wide range due to rainfall etc., it is necessary to level off the fluctuation of quantity and quality of leachate by setting up the leachate control pond. In addition to this, in order to mitigate loads of leachate through biological and physio-chemical treatment, preliminary treatment such as sedimentation or recirculation system will be effective to improve the quality of leachate.

Moreover, if sufficient landfill area is available, leachate treatment cost can be reduced by applying natural attenuation, which uses the functions of natural purification system to purify the leachate such as using the natural wetlands. On the other hand, if the landfill area is not sufficient or more advanced leachate treatment is required, more mechanized biological or physio-chemical treatment is necessary.

As references, examples of combination of different treatment processes are shown in **Figure II-32(a)** to **Figure II-32(d)**.

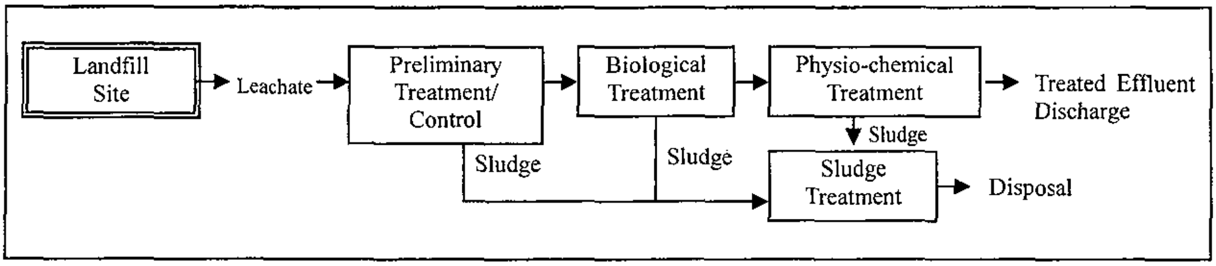


Figure II-32(a) Combination of Recirculation Process for Leachate Treatment (Recirculation + Bio-treatment + Physio-chemical treatment)

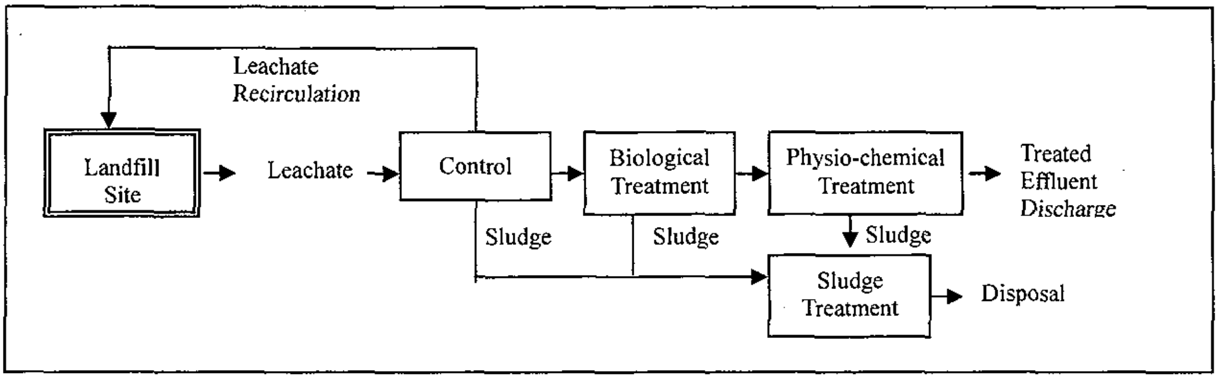


Figure II-32(b) Combination of Recirculation Process for Leachate Treatment (Recirculation + Bio-treatment + Physio-chemical treatment)

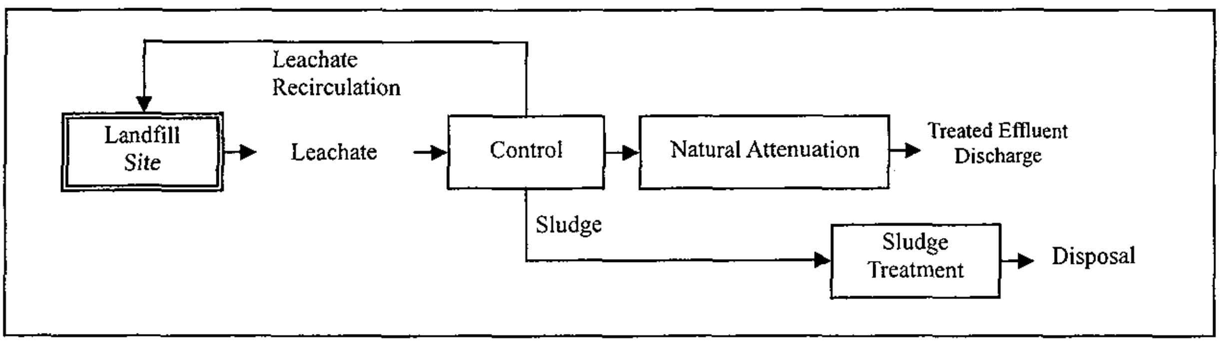


Figure II-32 (c) Combination of Recirculation Process for Leachate Treatment (Recirculation + Natural Attenuation)

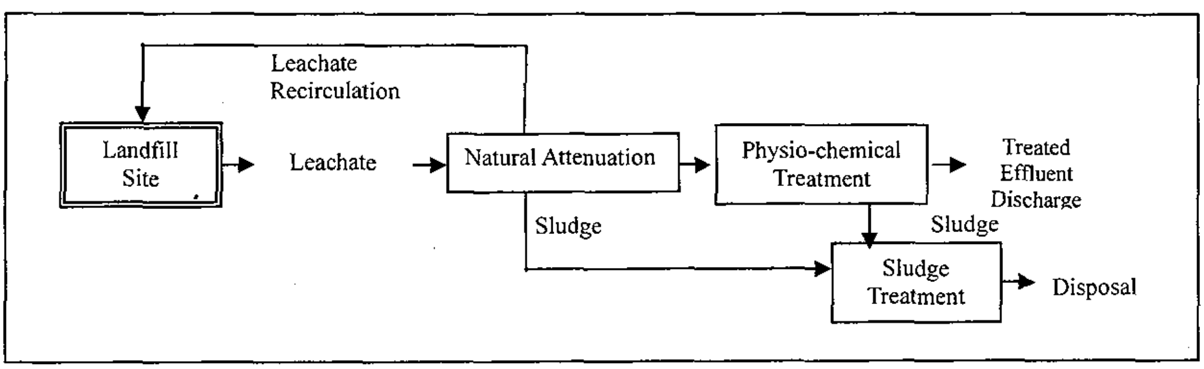


Figure II-32 (d) Combination of Recirculation Process for Leachate Treatment (Recirculation + Natural Attenuation + Physio-chemical treatment)

(1) Pre-treatment/Control Process

As pre-treatment, not only leachate control facility is required, but also others such as screen, grit chamber etc. for the removal of course matters, sediments, and control of leachate quality and quantity if required. In general, pH value of leachate from landfill site is within the middle range of approximately 6 to 8. However, sometimes pH is required to be controlled depending on the characteristic of landfilled wastes and cover soils. In case of high calcium concentration in leachate, measures to prevent generation of the scaling problems caused by calcium sulphite is necessary.

(2) Leachate Recirculation

Leachate recirculation is one of the treatment methods, which collects the leachate from the leachate control facility, then recirculate the leachate by sprinkling it over the surface of landfill layers again. The leachate quality will be improved by doing the recirculation due to the filtration and micro-organisms activities.

Although sometimes treated leachate quality is not able to comply with the DOE effluent standards by only doing leachate recirculation, however, it has the advantage of improving the leachate quality during the first treatment, which subsequently reduces the loads for the treatment at later stage such as biological or physio-chemical treatment processes. Example of the recirculation semi aerobic landfill system is shown in **Figure II-33**.

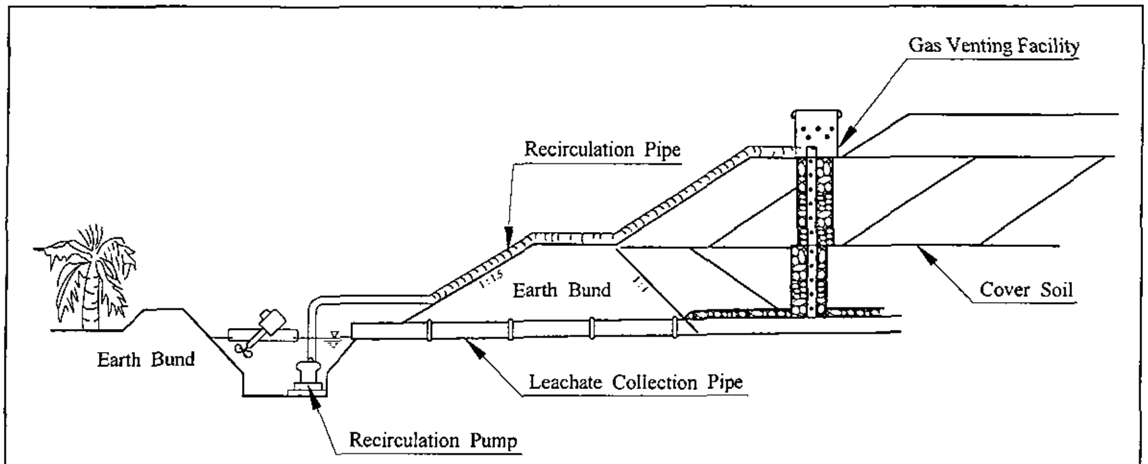


Figure II-33 Example of Recirculation Semi-aerobic Landfill System

(3) Biological Treatment Process

Parameters to be treated through the biological treatment process are such as BOD, COD and Nitrogen etc. Principal methods for biological treatment are aeration lagoon, activated sludge, contact aeration, rotary disk contact process, trickling filter etc. Type of methods to be used is determined in consideration of economical efficiency, treatment function, operation and maintenance, and other aspects.

(4) Physio-chemical Process

The parameters to be treated through the physio-chemical treatment processes are such as COD, colour, suspended solids, heavy metals, and total coliform etc. Principal methods for physio-chemical treatment are coagulation sedimentation, ozone oxidation, sand filtration, activated carbon adsorption, and chelating adsorption. It is necessary to consider combination of methods depending on parameters to be treated as well as the quality of treated leachate required.

Examples of physical treatment by using typical oxidation process (aerators) are shown in **Figure II-34.**

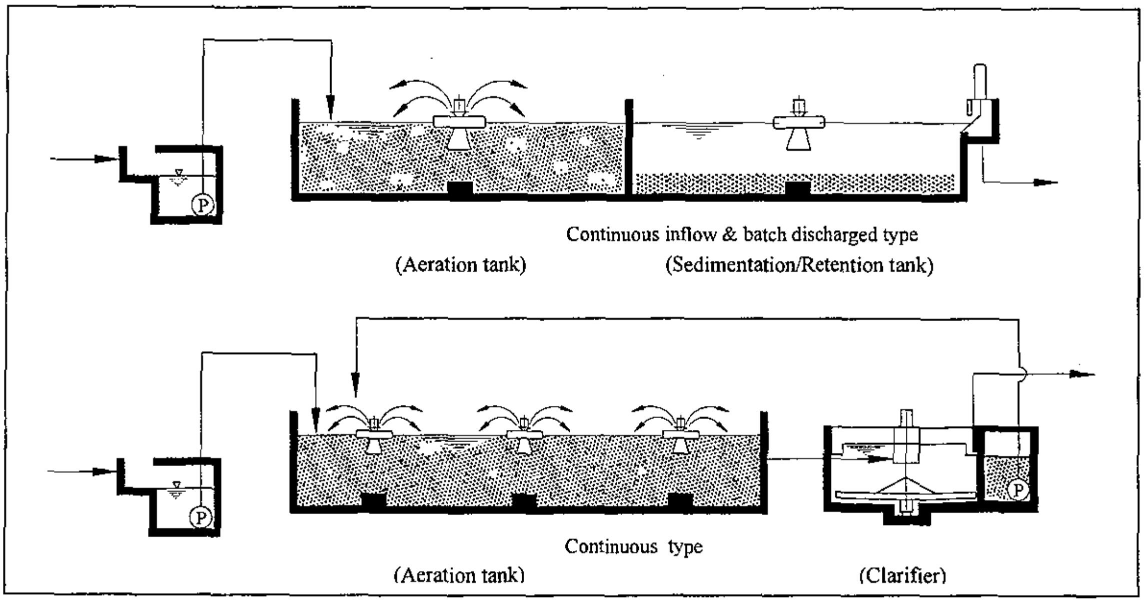


Figure II-34 Example of Flow Diagram for Typical Oxidation Process

(5) Natural Attenuation

Natural attenuation is a method of leachate treatment by utilizing purification function of the natural, which is usually possessed by ponds, wetlands, vegetation etc.

There is a possibility that the energy and cost required for the treatment can be reduced or the overall operation and maintenance process can be simplified by using natural attenuation treatment. However, this method needs certain extent of land area or water surface. If suitable condition is able to be well adjusted, the system can gain an advantage in terms of economic efficiency as well as resource recycling.

7.4.2 Treatment Method for Removal of Specific Parameters

The leachate treatment facility shall be designed with combination of treatment methods applicable to treat specific parameters as designed depending on the requirements since each particular parameter can be treated by using different methods of treatment.

Parameters to be treated are determined according to condition of each landfill site and surrounding environment. Basically, standard parameters as indicated by DOE are subject to be treated. Since each treatment method can treat different substances, it is necessary to design appropriate combination of treatment processes which is able to treat all desirable parameters so that the quality of the final treated leachate can comply with the regulated standards.

The general methods for leachate treatment and water quality items to which each method is applicable are shown in **Table II-18.** While the treatment methods applicable for the treatment of each particular parameter are described in the following sections.

Table II-18 The General Methods for Treatment of Specific Parameters

Methods \ Items		BOD	COD	Suspended Solids	Nitrogenous Compounds	Colour	Heavy Metals
Leachate Recirculation		++	++	++	+	+	+
Biological Treatment	Activated Sludge	+++	++	+	+	+	+
	Contact Aeration	+++	++	+	+	+	+
	Rotating Disk Bioreactor	+++	++	+	+	+	+
	Trickling Filter	++	++	+	+	+	+
	Aeration Lagoon	++	++	+	+	+	+
	Biological Filtration	+++	++	+++	+	+	+
	Biological Denitrification	+++	++	+	+++	+	+
Physio-chemical Treatment	Coagulation Flocculation	++	+++	+++	+	+++	++
	Ozone Oxidation	-	++	-	-	+++	-
	Sand Filtration	+	+	+++	-	+	-
	Activated Carbon Adsorption	+++	+++	++	+	+++	++
	Chelating Adsorption	-	-	-	-	-	+++
Natural Attenuation	Stabilization Pond	++	++	+	+	+	+
	Hydrosphere Treatment	++	++	+	+	+	+
	Wetland Treatment	++	++	++	+	+	+

Notes: +++ highly effective; ++ effective; + slightly effective; - not effective

(1) Biochemical Oxygen Demand (BOD)

The general methods for removal of BOD are given in **Table II-19.**

Table II-19 BOD Removal and Treatment Method

Treatment Method	Principle Action	Effectiveness
Leachate Recirculation	Biodegradation of organic wastes by microbes [micro-organism] in landfill layers	Can be used in wide range of leachate but its effectiveness varies depending on each landfill site
Biological Treatment	Biodegradation of organic wastes by microbes [micro-organism]	Can be used regardless of high or low (20 mg/L) concentration
Physio-chemical Treatment (Activated Carbon)	Absorption of soluble organic wastes by activated carbon particles	For low concentration only. (Less than 20mg/L)
Physio-chemical Treatment (Flocculation)	Flocculation and separation of SS components and soluble organic wastes	When SS components in BOD is very high
Natural Attenuation	Biodegradation of organic wastes by microbes [micro-organism] in catchments basin [stabilization pond], wetland etc. or aquatic plants	Can be used regardless of high or low concentration

(2) Chemical Oxygen Demand (COD) and Colour

The general methods for removal of COD and colour are given in **Table II-20**.

Table II-20 COD and Colour Removal and Treatment Method

Treatment Method	Principle Action	Effectiveness
Leachate Recirculation	Biodegradation of organic wastes by microbes [micro-organism] in landfill layers and absorption of soluble organic wastes by fine particles of soil at landfill site	Can be used in wide range of leachate but its effectiveness varies depending on each landfill site
Physio-chemical Treatment (Flocculation)	Create formation of floes and remove the colloids after sedimentation	Effective when molecular component of COD and colour is above 10,000
Physio-chemical Treatment (Activated Carbon)	Absorption of soluble organic wastes by fine particles of activated carbon	Can be used even when effectiveness is low because of its relatively low economic cost (Amount of discarded carbon shall be kept minimal
Physio-chemical Treatment (Ozone Oxidation)	Inject ozone to cause COD components to be oxidized	Effective way to remove colour. Appropriate as tertiary treatment process
Biological Treatment	Biodegradation of organic wastes by microbes [micro-organism]	Not effective if wastes are not easily biodegradable (such as products from metabolism of organic wastes)
Natural Attenuation	Biodegradation of organic wastes by microbes [micro-organism] in catchments basin [stabilization pond], wetland etc. or aquatic plants	Not effective if wastes are not easily biodegradable (such as products from metabolism of organic wastes)

(3) Heavy Metals

The general methods for removal of heavy metals are given in **Table II-21**.

Table II-21 Heavy Metal Removal and Treatment Method

Treatment Method	Principle Action	Effectiveness
Flocculation (Alkali Method)	Causes formation of hydroxides of metal and removed after sedimentation (pH of solution shall be alkali)	Appropriate for highly concentrated leachate (several mg/L)
Physio-chemical Treatment (Absorption Chelate)	Uses principle of absorption	Expensive method and suitable for removal of heavy metal in low concentration of leachate
Physio-chemical Treatment (Flocculation (with Additive))	Separation after sedimentation	Expensive method and suitable for removal of heavy metal in low concentration of leachate
Leachate Recirculation	Absorption of soluble organic wastes by cover or fine particles of soil in landfill layers	Can be used in for a trace amount of metals but its effectiveness varies depending on each landfill site
Natural Attenuation	Absorption and sedimentation of organic wastes by hydrosphere or wetlands, and ingestion by aquatic organisms	Can be used for a trace amount of metals but effectiveness is limited

(4) Nitrogenous Compounds

The general methods for removal of nitrogenous compounds are given in **Table II-22**.

Table II-22 Nitrogenous Compound Removal and Treatment Method

Treatment Method	Principle Action	Effectiveness
Leachate Recirculation	Evaporation of ammonia gas and removal of nitric acid by ingestion of vegetation	Can be used in wide range of leachate but its effectiveness varies depending on each landfill site
Biological Treatment (Biochemical Denitrification)	Ammonia is connected to nitric acid by nitrification bacteria. Nitric acid is then connected into nitrogen by the nitrogen releasing microbes	Applicable from high to low concentration of leachate
Physio-chemical Treatment (Absorption)	Absorption of ammoneous compounds geolide or other inorganic nitrogenous compounds by activated carbon	Effective only for relatively low concentration of leachate
Natural Attenuation	Ingestion, nitrification and nitrogen releasing, absorption, sludge precipitation by aquatic organisms or algae, and evaporation of ammonia into atmosphere	Applicable from high to low concentration of leachate

(5) Suspended Solids (SS)

The general methods for removal of suspended solids (SS) are given in **Table II-23.**

Table II-23 SS Removal and Treatment Method

Treatment Method	Principle Action	Effectiveness
Leachate Recirculation	Filter off SS components through cover or fine particles of soil in landfill layers	Can be used in wide range of leachate but its effectiveness varies depending on each landfill site
Physio-chemical Treatment (Sedimentation)	Settling particles under normal condition or after flocculation	Suitable for leachate with several hundred mg/L to several thousand mg/L of SS
Physio-chemical Treatment (Filtration)	Filter off SS components through a layer of sand	Suitable for leachate with several hundred mg/L to several thousand mg/L of SS
Natural Attenuation	Gravitative precipitation of particles at hydrosphere and wetlands	Suitable for leachate with several hundred mg/L to several thousand mg/L of SS

7.4.3 Outline for Each Treatment Method

There are various types of leachate treatment methods. It is necessary to design suitable process for each treatment methods by taking into consideration the characteristics and applicability of each method.

Leachate treatment methods are roughly classified into several types, i.e. leachate recirculation, biological treatment, physio-chemical treatment and natural attenuation etc. For each method, applicability, facility cost or expenses, operation and maintenance, area required for construction, and other conditions are different.

Based on characteristics of each method, the most appropriate and rational treatment system shall be designed for a particular landfill site.

(1) Recirculation System

Leachate recirculation is a method using the landfill site itself as bioreactor. It collects leachate from the leachate control facility, and then recirculate the leachate by sprinkling it over to the surface of the landfill waste layers.

Collection of leachate by the leachate collection pipes and storage of leachate at leachate control pond are prerequisite for leachate recirculation as well as other treatment methods.

As pre-treatment, supplying oxygen to leachate by aeration process will accelerate the decomposition process by micro-organisms and it will be effective in reduction of offensive odour from the landfill site.

Leachate pumped up from leachate control pond can be recirculated by various methods:

1) To sprinkle leachate directly on the surface of the landfilled waste layers by spray nozzle
2) To sprinkle leachate into the some trenches excavated on the landfill surface of the landfilled section
3) To set a leachate pond on the surface of the landfilled waste layers
4) To set vertical injection well on the landfill site such as using gas venting pipes as the vertical injection well

Leachate recirculation system can lower the oxidation-reduction potential of the leachate and make micro-organisms active so that various types of organic pollutants can be decomposed and reduced. Moreover, as far as heavy metals are concerned, heavy metals will be washed out by leachate recirculation and immobilized simultaneously as hydroxide or sulphide compounds. In addition, physio-chemical reaction such as adsorption, ion exchange, filtration, containment etc. are able to capture heavy metals effectively.

However, it is hard o control the chemical reaction in the landfill site and leachate recirculation system cannot guarantee the expected quality of treated leachate. For this reason, it is also desirable to implement biological treatment and physio-chemical treatment at the same time.

Conversely, when biological or physio-chemical treatment is in planned, it is expected that leachate recirculation system as pre-treatment can definitely improve the leachate quality and lower the loads of the treatment processes. Therefore, it is desirable to recirculate the leachate if possible.

Recirculation of leachate can also accelerate decomposition of landfilled wastes and stabilization process of the landfill site. In terms of accelerating the stabilization process, uniform stabilization can be achieved by recirculating the leachate into the landfill layers at more than one point by changing the recirculation points at a regular interval. In this case, operating the landfill site in semi-aerobic conditions will enable organic materials to be decomposed effectively.

(2) Biological Treatment

The biological treatment applied to mechanical leachate treatment at landfill site is representative of water treatment methods such as activated sludge process, contact aeration process, rotating disk bioreactor etc. In general, concentration of organic substances included in leachate tends to decrease as landfill work progresses from the early stage through middle stage to the final stage. Therefore, it is necessary to design a biological treatment plan in consideration of the characteristics of the age of the landfilling work.

The micro-organisms' activities for biological treatment become active in the high temperature region, and it changes as fluctuation of atmospheric temperature. Therefore, biological treatment needs to be designed by referring to cases that are under similar meteorological conditions and making an investigation on the multiplication rate or growth conditions of the micro-organisms.

Leachate is sometimes short of phosphorus which enhances the biological treatment process. Lack of phosphorus to organic carbonate sources such as BOD, may cause inhibition of biological treatment. Therefore, in some cases, facility to add phosphorus equivalent to BOD needs to be set up. Phosphorus is added in the form of phosphoric acid and standard dosage or ratio of phosphorus to BOD is about 1/100.

a) Activated Sludge Method

Activated sludge method is the treatment of floating biological treatment process. It consists of aeration basin and sedimentation basin. Generally, it is expected that high removal rate of organic matters will be achieved by long hours of aeration. Unlike night soil or sewage, leachate quantity and quality may fluctuate widely. Therefore, structure of the activated sludge treatment facility shall be able to manage mixed liquor suspended solid (MLSS), sludge volume index (SVI), dissolved oxygen (DO) etc.

b) Contact Aeration Method

Contact aeration is a treatment method that fills the aeration basin with contact filter media, stirs the leachate in the aeration basin with aerator, supplies enough oxygen to the basin, and removes organic matters in the leachate by biological membrane which forms at the surface of the contact filter media.

There are various shapes of contact filter media, such as saddle-back shape, honeycomb shape, cylindrical shape, laminated corrugated plate shape etc. Each shape shall have a design that does not cause blockage by biological membrane and biological membrane can easily adhere to.

Not only hydrostatic pressures but also hydrodynamic pressures are applied onto the filter media due to the stirring of leachate in the contact aeration basin, and the loads by formation of biological membrane is also applied onto the filter media. In consideration of these conditions, filter media shall have enough strength of structural durability.

c) Rotating Disk Bioreactor

This method removes organic matters such as BOD substances in leachate by micro-organisms adhering to the surface of the rotating disk bioreactor installed in the storage tank. Facility of this system consists of a rotating disk bioreactor and its cover, and running gears. Hard chloroethene or polyethylene is generally used as materials of rotating disk bioreactor. Fibreglass reinforced plastic (FRP) and polystyrene can also be utilized.

In each case, synthetic resins which have corrosion proof and halophytic characteristics shall be used as materials.

There are various shapes of rotating disk reactor such as quarter sector block concavo-convex shape, flat plate shape, flat plate concavo-convex shape, corrugated plate shape, double corrugated plate shape etc. Each shape shall satisfy the following conditions:

- It shall not be corroded or deformed by contact with leachate or micro-organism.
- It shall has a structure which biological membrane can easily adhere to and proliferate
- It shall not cause blockage readily.

d) Trickling Filter Method

This method makes aerobic bacteria which correspond to activated sludge adhere to the surface of filter media (corrugated polyvinyl chloride plate or crushed stone) and proliferate, so that organic matters is adsorbed to the surface of filter media and decomposed when the leachate is sprinkled.

Trickling filter method is easy to operate and maintain, and it is strongly adaptable to conditions with fluctuation of leachate quantity and quality. However, removal rate of organic matters is inferior to activated sludge method. Therefore, it is necessary to adopt double trickling filter or prevent clogging of filter caused by inflow of suspended solids. This method is also easily affected by external temperature.

In general, more than two filter beds are installed for the trickling filter. It shall not impede the operation and maintenance of the facility. The number and structure of filter beds may widely change depending on influent conditions as well as the filter media used.

Crushed stones and synthetic resins are commonly utilized as materials for filter media. Synthetic resins are classified into two types: one is integral moulding type; and the other is monadelphous moulding type such as crushed stone.

In case of crushed stone and monadelphous moulding contact filter media, since sprinkled leachate is diffused speedily, the depth of the filter beds become shallow. On the other hand, when integral moulding contact filter media is used, diffusion of leachate does not progress as quickly as crushed stone and the depth of filter beds become deeper. However, surface area per unit volume becomes larger and BOD load increases.

In general, circulation ratio (circulated volume/influent volume) of crushed stone is above 100%, and that of monadelphous moulding type is above 200%. It is therefore recommended that if circulation ratio is over 400%, the system is considered non-economical and inefficient.

e) Aeration Lagoon Method

Aeration lagoon method is one of the floating biological treatment methods which minimizes organic loads of activated sludge method to aeration basin as small as possible and make longer detention time of aeration basin.

Because of the large amount of aeration capacity, there are defects that buffer action to temporary fluctuation of quantity and quality of leachate may increase, the treatment process can be easily affected by external air temperature.

When inflow BOD concentration is low, sometimes it is difficult to keep the MLVSS, namely bacteria forms such as BOD oxidation bacteria.

Surface aerator aeration method is popular used as aeration method, but air blower method is also used in some cases.

f) Biological Filtration Method

Biological Filtration is a method which macerates silica rock, porous ceramics or other specific filter media in the aeration basin, then filtrate the leachate slowly supplied with oxygen at the top or the bottom of the filter media, and finally carries out the biological oxidizing decomposition of organic materials and filtration of suspended solids.

Particle diameter of filter media material is approximate 5 to, 70mm. When selecting filter media, it is necessary to consider the inflow leachate quality, purpose of the treatment, frequency of backwash and other conditions.

Biological filtration treatment can be applied as tertiary treatment. Aeration of this method is done by air blower in principle.

g) Biological Denitrification

Biological denitrification is one of the typical methods which remove the nitrogenous contents included in the leachate.

The basic principle of biological denitrification consists of two-step chemical reaction: The first step is nitrification of ammonium-nitrogen, the second is denitrification by gasification of nitrite-nitrogen and nitrate-nitrogen. Sometimes a re-aeration basin is installed to reduce organic carbon sources such as residual methanol.

There are several factors affecting nitrification: water temperature, pH, concentration of substrate (NH_4^+-N), dissolved oxygen (DO) in the tank, ammonium-nitrogen loads, nitrogen oxide load, alpha value (ratio of injected ammonium-nitrogen to nitrogen oxide) etc. It is desirable that the facility has a structure which regulates the specific factor if necessary. Besides, since nitrification process depends heavily on temperature, structure of treatment facility needs to be modified to prevent the leachate temperature from going down.

For effective denitrification process, structure of treatment facility shall have anaerobic zone in the basin and is able to supply enough organic carbon as energy sources for denitrifying bacteria.

(3) Physio-Chemical Treatment

a) Coagulation, flocculation and sedimentation

Coagulation and flocculation treatments are done by adding coagulant and auxiliary coagulant. Ferum chloride, aluminium sulphate and polychlorinated aluminium are commonly used as coagulant. On the other hand, polymer coagulant is used as auxiliary coagulant. Generally, ferum chloride has wide applicable pH range and its removal effect of COD and colour is bit superior compared with aluminium salts. However, aluminium salts are less corrosive than ferum chloride, so that it has no effect on the materials of chemical tank used. Furthermore, because of its low acidity, amount of neutralizing agent required is less.

During coagulation, pH setting is divided into three ranges: acidic range (pH=5 to 6); neutral range (pH=7 to 8); and alkali range (pH=9 to 10).

Acidic range shall be suited to enhance COD removal ratio, and to remove heavy metals, alkali range is more suitable.

b) Sand filtration method

There are two types of sand filtration methods, fixed bed type and moving bed type. Fixed bed type has two categories, gravity type and pressure type. This method is able to lower the suspended solids concentration below 10mg/L and be used as pre-treatment before the activated carbon adsorption or chelating adsorption process.

c) Activated carbon adsorption

Activated carbon adsorption is applied in advanced treatment for removal of COD and colours. Granulated activated carbon is generally used because powder activated carbon is complicated to handle.

d) Chelating adsorption

Chelating adsorption is carried out in order to achieve better treated leachate quality, after the coagulation, flocculation, sedimentation, sand filtration and activated carbon adsorption processes are carried out. Moreover, by chelating adsorption process, heavy metals can be removed. Chelating resin can be classified into two types: one is for adsorption of mercury; and the other is for adsorption of general heavy metals. Both types of resin are able adsorb and remove heavy metals.

e) Ozone oxidation method

Ozone oxidation method is more effective in reducing colour rather than COD. In this case, this process will take more effect only when combination of pre-treatment with coagulation and sedimentation are carried out.

(4) Natural Attenuation

There are several kinds of natural attenuation that can be used as treatment system for leachate quality purification: systems using stabilization pond (oxidation pond), systems using hydrosphere treatment such as floating plants and systems using wetlands.

Each natural attenuation system basically depends on natural physio-chemical reactions and specific biological elements in each process. As compared to controlled biological treatment or physio-chemical treatment, its reaction velocity is slower, and it requires relatively large areas due to its longer detention time.

If the leachate is directly poured into a wetland surrounding a landfill site, it will be no different from discharging untreated leachate and the risks of pollution for the surrounding environment will become much higher. Therefore, it is important to set a natural attenuation area within the landfill site and control the discharged leachate quality consciously. In addition, leachate quality discharged into the public water bodies shall be monitored constantly.

a) Leachate stabilization pond

Leachate stabilization pond is the treatment method which purifies the leachate by using interactions of various biological species in the pond. It is categorized into facultative anaerobic stabilization pond, aerobic stabilization pond and anaerobic stabilization pond depending on the kinds of dominant biological reactions, period and frequency of discharge treated leachate, degree of pre-treatment, and sectional arrangement of the ponds. Among these, facultative anaerobic stabilization pond is most commonly used as oxidation pond, lagoon or photosynthetic stabilization pond.

Facultative anaerobic stabilization pond is generally 1.2 to 2.5m depth. Upper layer is aerobic, lower layer is anaerobic, and bottom layer is accumulated sludge layer. Detention time of the pond is usually about 5 to 30 days. Anaerobic fermentation occurs in lower layer, on the other hand, aerobic stabilization occurs in upper layer. Significant considerations for operation of facultative anaerobic conditions are the generation of oxygen by photosynthesis and re-aeration of the surface. Oxygen is used for stabilization of organic matters by aerobic bacteria at the upper layer. Although algae is indispensable for oxygen generation, remaining algae in treated leachate at the final stage will deteriorate the treatment efficiency. This is the most common problem faced on deterioration of treatment efficiency at facultative anaerobic stabilization pond.

Aerobic stabilization pond (also known as high-speed aerobic stabilization pond) keeps dissolved oxygen (DO) at every depth of the layers. The depth of aerobic stabilization pond is generally 30 to 40m. It is important to ensure that the sunlight can reach every depth of layers. In many cases, mixing is done so that sunlight can reach all the algae, which prevents decomposition of algae and being anaerobic. Photosynthesis and re-aeration of the surface will supply oxygen, subsequently the aerobic bacteria will purify the leachate. Its retention time is relatively short, i.e. about 3 to 5 days.

Anaerobic stabilization pond is used for leachate with high organic loads, at which aerobic condition may not exist as pre-treatment to reduce the loads at the latter treatment process. The depth of anaerobic stabilization pond is about 2.5 to 5m and retention time is about 20 to 50 days. Main biological reactions in the pond are generation of acids and methane fermentation.

b) Hydrosphere Treatment

This method uses purification function of hydrosphere environment such as aquatic plants, aquatic animals, plankton, and submerged plants for the leachate treatment process.

For example, by using floating grass such as water hyacinth or duckweed, it is possible to remove BOD, SS, and nitrogenous compounds effectively. In particular, water hyacinth is photosynthetic plants with high reproductive power, which has advantage as the leachate treatment system. Moreover, it has effective effect in the removal of heavy metals and trace amount of organic matters by chemical sedimentation and absorption at the substrate and surface of the plants.

The principal problems faced for the operation and maintenance of this treatment are the proliferation of mosquitoes, offensive odours, control of plants, removal of sludge, and reaping of plants. Disposal or reuse of reaped plants and removed sludge are also important elements of operation and maintenance.

c) Wetland treatment

This is a treatment method at natural or artificial wetlands by using natural water purification function of wetlands. However, using directly the natural wetlands for leachate treatment is dangerous especially it may changes the growth conditions of plants and animals in the wetlands. Basically, in order to avoid environmental pollution of natural wetlands, it is desirable to construct artificial wetlands if possible. This will enable the design of suitable wetlands which keep the proper slope of bottom layer and control the leachate flow. Artificial wetland is divided into two categories, one is FWS (Free Water Surface) wetland of which the water surface is exposed to the atmosphere, and the other is SF (Subsurface Flow) wetland, which keeps the water level below the soil surface by using permeability materials.

At the FWS wetland, water surface verges on the atmosphere, there is a soil layer at the bottom of the pond for emerged vegetation and space for taking root, lining facility is set for prevention of groundwater if necessary, and appropriate influent/effluent facilities are constructed. Water depth of the wetland is a few cm to 1m depending on purpose of the treatment. Generally, 0 to 3% of bottom slope is required.

At the SF wetland, excavated pond is filled with supporting substrates such as sand filter, and water level is kept below the upper surface of sand filter layer. Vegetation is planted on the top of the sand filter layer, and lining facility is required to prevent the groundwater if necessary.

In both types of artificial wetlands, it is considered that biological reaction is generated by periphyton. SF wetland uses sand filter as bed, so that surface area of SF wetland becomes larger than the FWS wetland. The larger surface area will accelerate the reaction velocity so that necessary land area is relatively small.

Wetland treatment is able to effectively treat the highly concentrated BOD, SS and nitrogenous compounds. It is also effective in removal of heavy metals as well as trace organic matters. From operational and maintenance points of view, control of proliferation of mosquitoes and plant management are important.*

(5) Sludge Treatment

Sludge generated from biological and physio-chemical leachate treatment has high moisture contents and not suitable for landfilling. Therefore, sludge needs to be treated through thickening, storing and dewatering processes.

* S.C. Reed, R.W. Crites, and E.J. Middlebrooks : Natural Systems for Waste Management and Treatment (1995)

a) Sludge Thickening

Sludge thickening process used for leachate treatment is divided into gravity thickening and centrifugal thickening.

Gravity thickening is a method which separates and settles the flocculated sludge by gravity. Generally, structure of thickener in small capacity is hopper type, and that in medium to large capacity is scraper type.

Centrifugal thickening a mechanical thickening process which inserts the sludge into the drum rotating at high velocity, and its centrifugal force will separate the liquid and solids and subsequently thicken the sludge.

b) Dewatering

Thickened sludge is mechanically dewatered by using dewatering facility to lower the moisture contents, and landfilled as dewatered cake. In order to dewater the sludge more effectively, thermal refining work is usually done in advance. There are inorganic and organic thermal refining materials.

Inorganic thermal refining materials include lime, iron chloride, ferrous sulphate, ferric ammonium sulphate, polychlorinated aluminium etc. Organic thermal refining materials are such as polymer coagulants. It is necessary to select specific thermal refining material and control its injection rate considering the characteristics of sludge and dewatering method applied.

There are several types of dewatering machine such as centrifugal dewatering, belting press dewatering etc. It is necessary to select a suitable dewatering process by taking into considerations the operational conditions such as the types of sludge, moisture contents of dewatering cake, capacity of the treatment facility etc.

Similar with centrifugal thickening, centrifugal dewatering is a method which inserts the sludge into a rotating drum in high velocity, and then separates the solid and liquid and dewater the sludge by centrifugal force. Although the moisture content of the dewatered sludge cake is relatively high by using this method, the facility usually equipped with a hermetically sealed structure to eliminate the odours.

Belting press dewatering method is a method that inserts the sludge into a fabric filter between two filter fabrics, and then compress for dewatering. The moisture contents of dewatered cake by using this method are relatively low and noise and vibration generated are also less.

7.5 Operation and Maintenance for Leachate Treatment Facility

Leachate treatment facility will be able to function efficiently only if it is properly operated and maintained with an effective operation and maintenance plan. The maintenance of the leachate treatment facility in particular, shall be implemented not only during the landfilling process but also after the completion of landfilling.

(1) Operation and Maintenance of Leachate Treatment Facility

When designing a leachate treatment facility, one of the most basic factors to be considered is easy maintenance and management. Unlike night soil or sewage, leachate volume and quality are changing with weather and seasons. These changes are sometimes on a short term and sometimes on a seasonal basis. Therefore, leachate treatment facility shall be able to cope with both cases.

Landfilled wastes decompose by time and this causes the leachate quality to also change throughout the years. Measures to monitor the leachate quantity and quality as well as regular checking and maintenance of each component of the treatment facility are necessary. In other words, maintenance is a very important factor in the operation of leachate treatment facility.

Leachate characteristics shall be fully understood when considering the leachate quality changes with time by using the molecular weight distribution characteristics as shown in examples in **Figure II-35**. From this figure, there are 5 distribution patterns for the leachate molecular weight. As the landfill site stabilizes, the molecular weight distribution changes from Stages I to V.

The leachate quality deteriorates during the initial stages (Stage I) of landfilling when the leachate is trapped within the landfill layers. Ultraviolet rays absorption can be observed over a wide range of molecular weight and concentrations of BOD and COD can be estimated. As Stages II and III develop, decomposition of organic matters advances and the phenomenon of decomposition into lower molecular weights occur. Three peaks can be observed in Stage III. At Stage IV, the low molecular weights area becomes smaller and moves closer to the lower molecular weights area suggesting a leachate quality with BOD/COD lower than 1. Stage V is the final landfilling stage before completion and the peaks of the molecular weights area are even lower.

Management and maintenance policies developed for leachate treatment facility based on the molecular weights characteristics obtained from the changes of leachate with time, would be extremely cost effective and efficient.

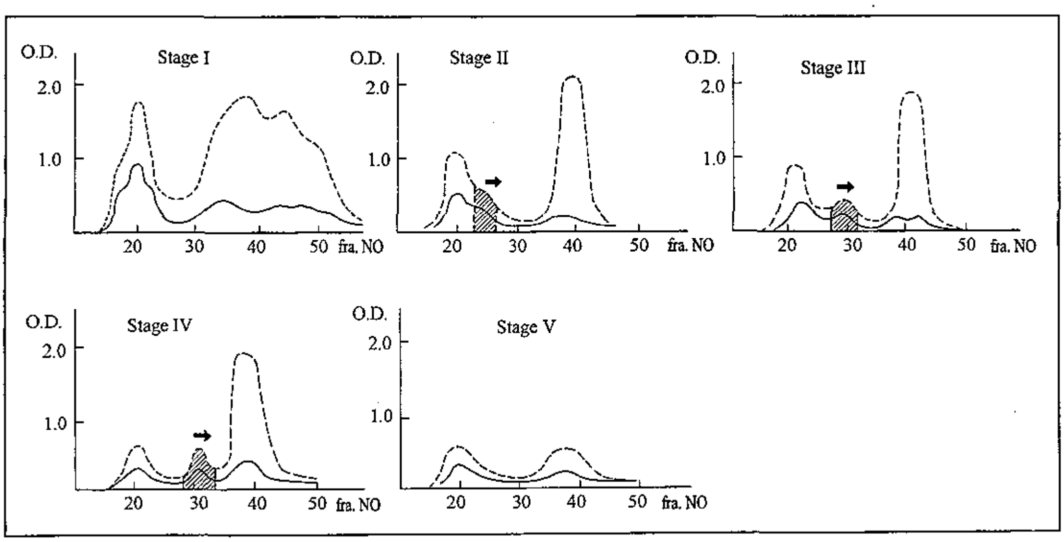


Figure II-35 Fluctuation of Molecular Weight With Landfilling Schedule

Therefore, for proper operation and maintenance of the leachate treatment facility, the following measures at different landfilling stages shall be considered:

a) Initial Stage of Landfilling

- At this stage, silt, sand and soil flowing into the landfill site is extremely high and therefore, a sand settling pond shall be installed.
- Since the concentrations of organic matters are extremely high, leachate quality analysis shall be performed and sufficient amount of oxygen shall be supplied to the biological treatment process.
- The amount of biodegradable substances is high and biological treatment will be the main process, thus these factors have to be given due considerations.

b) Middle to Final Stages of Landfilling

- The concentration of suspended solid in the leachate is stable but the amount of non-biodegradable substances increases, therefore the conditions for solidification and precipitation shall be readjusted.
- The frequency of brush cleaning, ultrasonic cleaning etc. shall be increased and properly adjusted as a scaling adjustment for pH, ORP, DO meters etc.
- Sludge shall be properly removed or concentrated in the settling pond and at the same time, proper aeration shall be done to prevent putrefaction in the sludge storage tanks.

c) Seasonal Operations

i) Dry Season

- During dry season, aeration in the activated sludge process, contact aeration process and biological filtering process shall be reduced. Revolution of rotary bio-disk conductor process shall be adjusted in the trickling filter process. The discharge volume of the circulating pump shall also be adjusted so as to sufficiently aerate the inflowing water level.
- Whichever process used, one of the most basic factors to take into consideration is that the operational coefficients shall match with the leachate volume to be treated.
- In the rotary bio-disk conductor process and the trickling filter process, the filter shall be properly cleaned and the leachate in the tank shall be removed.
- When a part of the facility is shut down in the case of activated sludge process or contact aeration process, the leachate in the tank shall be completely removed or properly aerated to prevent putrefaction.
- During dry season, the bacteria inside the tank shall be protected by either mixing the biologically treated leachate or by feeding a nutrient source.

ii) Monsoon Season and Heavy Rain

- The gate or sluices to control the amount of leachate inflow into the treatment facility shall be adjusted. Leachate can be recirculated into the landfill site if necessary.
- Other related facilities shall be adjusted so that the flow volume control capacity can

be maximized.

- The aeration in activated sludge process and contact aeration process shall be increased to ensure that there is sufficient oxygen in the biological reaction tank. The revolution of the rotary bio-disk conductor process while in the trickling filter process shall be adjusted, and the discharge of the circulating pump shall be adjusted to sufficiently aerate the inflowing loads.

(2) Recording of Operational Data

When maintaining a leachate treatment facility, actual data on the operation shall be recorded. This data will not only be important when considering cost effective operation methods but also play a major role when designing any new facilities. The following are some main data that shall be properly recorded and kept:

- Leachate Volume – Raw leachate volume and discharged leachate volume.
- Leachate Quality – Raw leachate quality and treated leachate quality.
- Weather conditions – Daily rainfall volume, temperature, wind velocity, humidity etc.
- Operational data – types and volume of chemical used etc.