Appendix 4.2 Collection method and collection equipment

(1) Collection method

i) Door-to-door collection and station collection

To the collection of solid waste from small-volume dischargers such as households, small shops, small restaurants, etc., either the door-to-door collection method or station collection method is applied.

In the door-to-door collection method, collection workers visit every discharger and collect the solid waste.

In the station collection method, the dischargers bring their waste-filled containers up to specified stations on the designated days and bring their empty containers back home after the collection.

Stations are constructed along roads, the location of which are determined considering the distance between the station and dischargers (average distance for dischargers to bring their containers) and the required capacity of the station.

ii) Frequency of solid waste collection

The collection frequency can be reduced if proper solid waste containers in terms of shape and quality are prepared by every discharger. Eventually, the reduction of the collection frequency also reduces the collection cost substantially.

From a hygienic point of view, however, garbage and other quickly decomposable waste should be collected at least once a week. Solid waste from restaurants and other commercial sectors should be collected several times a week because they contain a large volume of biodegradable material.

(2) Collection equipment

i) Hand tools

In performance of door-to-door collection, collection trucks are not always able to approach to every doorway. When approach is impossible, the solid waste container is carried by a collection worker from each house to a collection truck; the contents of the discharger's container are emptied into a transit container which is hauled to the collection truck by push cart or other equipmnet.

ii) Collection trucks

Barges are often used as collection vehicles, but use of collection truck prevails.

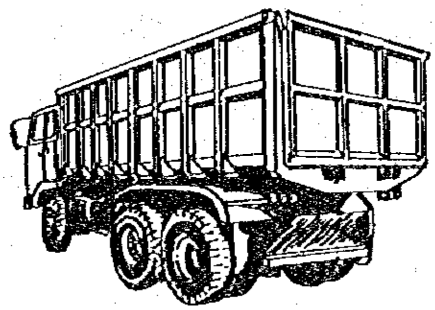
Most collection trucks are equipped with solid waste loading equipment. Although the collection trucks without loading equipment are inexpensive, manual loading of solid waste forces collection workers to engage in dangerous work such as lifting heavy solid waste containers up over the sides of a collection truck, and in addition, loading efficiency is low. The collection trucks with loading equipment are classified according to the modes of loading: a rear loader, a side loader or a front loader.

Solid waste compaction equipment is attached to most collection trucks for the higher carrying capacity. Unloading is done by either dump mechanism or forcible unloader which pushes loaded solid waste off with an unloading blade. Currently the most typical collection truck is a compaction-equipped rear loader (hereafter referred to as a compactor). The type of compactor varies as follows: rotary disc type, lift board type, rotary type, press type and thrust press type. Some of the press type compactors are specially designed for packing of bulky waste using high press power.

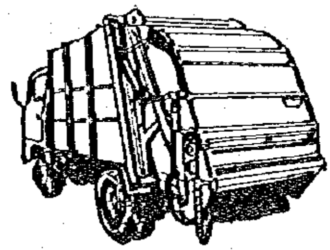
Normally, two or three collection workers are assigned per compactor.

Some major types of collection trucks are shown in figure AP 4.2.

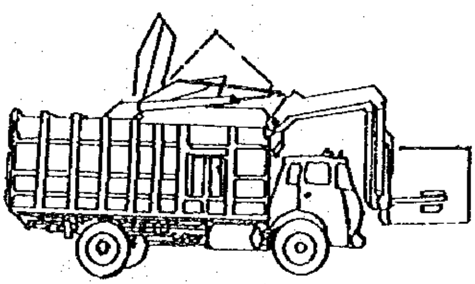
Fig. AP 4.2 Collection truck types



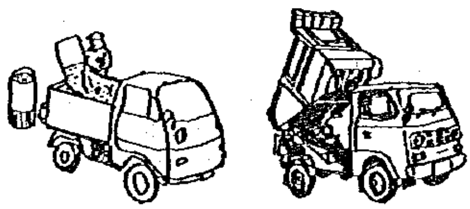
Dump truck with high sides



Compactor (rear loader)



Dump truck with front-end loader



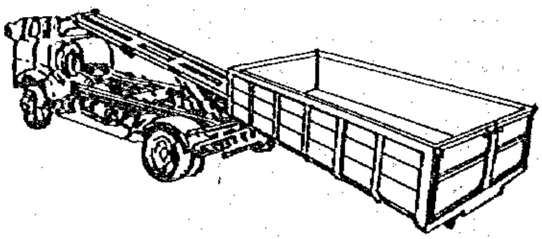
Light dump truck

iii) Container trucks

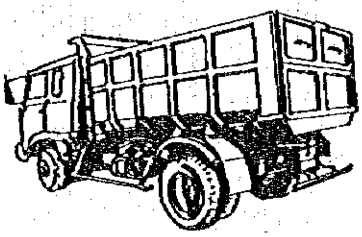
Container collection systems are divided into stationary container system and hauled container system.

In the stationary container system, solid waste in a small size container (approx. 1 m^3) is mechanically dumped on to a collection truck and the emptied container is returned to its original collection position. Container trucks for this purpose consists of two types: one is a common compactor equipped with a container roll (turn over) device, and the other is a dump truck equipped with a crane.

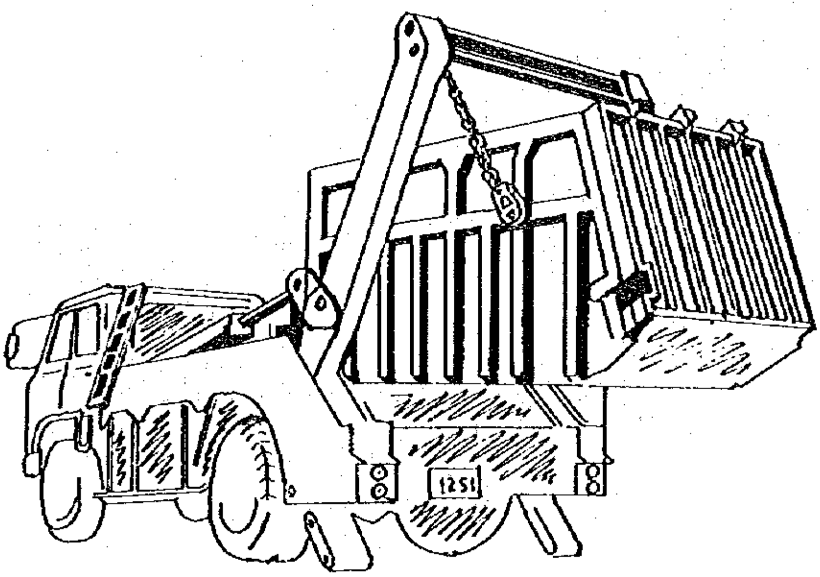
Fig. AP 4.3 Collection and transport vehicles for container collection systems



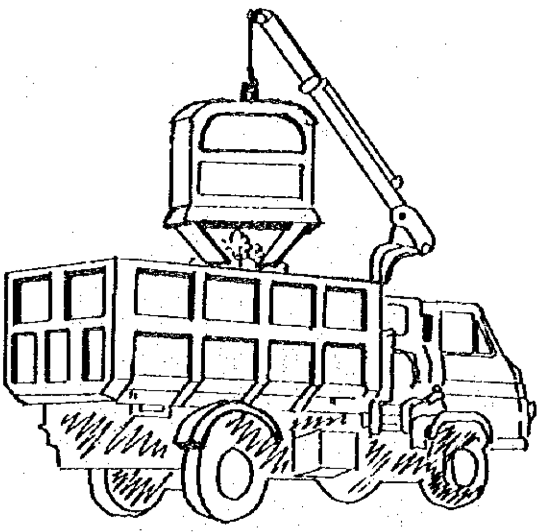
Container loader (tilt loader)



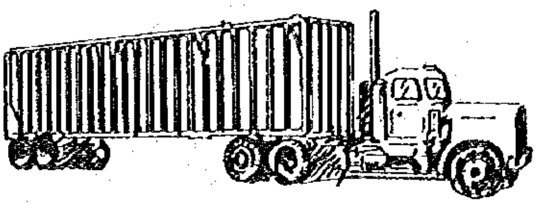
Container loader (arm-roll type)



Container loader (lift arm type)



Container-crane truck



Container trailer

The small containers should have wheels to facilitate conveyance.

In the hauled container system, large size containers filled with solid waste are transported by special container vehicles to processing or disposal sites. After the solid waste is dumped, the container is returned to service at either its original location or some other location. For this purpose, container loaders are used. The types of container loader can be classified according to the function such as tilt loaders, lift-arm trucks, arm-roll trucks, etc. A collection trip of a hauled container can be operated by a driver alone; however, for effective operation of the system, the trip schedule should be planned to avoid transporting unfilled containers. Some examples of collection trucks for container collection systems are shown in figure AP 4.3

iv) Pipeline collection and transport system

The solid waste inlets for the pipeline are located at each discharge source. Solid waste thrown into the inlet is carried through the pipeline by compressed-air force or by vacuum force to processing or disposal sites or transfer stations. This system has many advantages and disadvantages as follows:

Some of advantages are:

- Solid waste is hygienically handled.
- The system is automatically operable so that labour saving are easily realizable.
- Mass solid waste transportation is possible.

Disadvantages are:

- It requires a large investment particularly when it is to be introduced to already-urbanized areas.
- Alteration or extension of the pipeline is difficult; compared with truck transport, the system is inferior in the flexibility; however, it may be worthwhile to consider introduction of pipeline collection and transport system when planning construction of a new town with multiple-storied buildings, hotels, hospitals and office buildings.

Appendix 4.3 Transport method and equipment

In the most cases, collection trucks are used as transport equipment. When a transfer system is adopted, transfer of solid waste from collection trucks to larger conveying trucks or barges is often made to reduce the unit transport cost.

(1) Evaluation of setting up a transfer station

A main purpose of setting up a transfer station is to reduce the collection and transport cost.

Opinions about economic break even point for transport distance in the transfer method differ; some say that the transfer method is economical when a transport distance is 6 km or longer while the others say 20 km-distance is minimal.

According to the Study team's estimation, the minimum transport distance to make transfer method economical was 12 km.

In the estimation, two cases of transport were compared each other using a simple mathematical model: case one is to transport solid waste directly (without transfer) to the destination with the existing 7.5 m^3 compactors, and the other case is emptying solid waste collected at a station by a compactor into a 10-ton container which is hauled to a processing or disposal site. The results of the estimation indicate that it is worthwhile to study the applicability of the transfer method when the processing or disposal site is located far remote from the collection areas.

In some cases, resource recovery equipment or volume reduction by pulverization or baling is attached to transfer stations. It is basic, however, that transfer stations must be set up in areas from which a large volume of solid waste is generated, that is to day, in the densely populated city area. Therefore, if resource recovery, pulverization or baling is planned at a transfer station, there should be proper facilities to prevent diffusion of rank odour, noise and vibration generated by the pulverizer and classifier.

As the result, the transfer station will be forced to have some auxiliary facilities and, in the extreme case, the transfer station will be not so much different from a small processing station. A view of a transfer station is shown on Fig. AP 4.4 and a conceptual diagram of the transfer system is shown on Fig. AP 4.5.

(2) Transportation equipment

The following machines are used as solid waste transport equipment:

Heavy duty trucks with carrying capacity of 8 ton or heavier, container trucks or container trailer trucks with a capacity from 15 to 50 m^3, boats, ships, barges, trains, pipelines, etc.

Some types of heavy duty trucks are equipped with compacting devices for the higher loading capacity.

The container system is suitable when mass-transport is desired. Use of vessels is sometimes beneficial in a mass-transport system. However, there are few cases of solid waste transport by rail.

Fig. AP 4.4 View of a transfer station

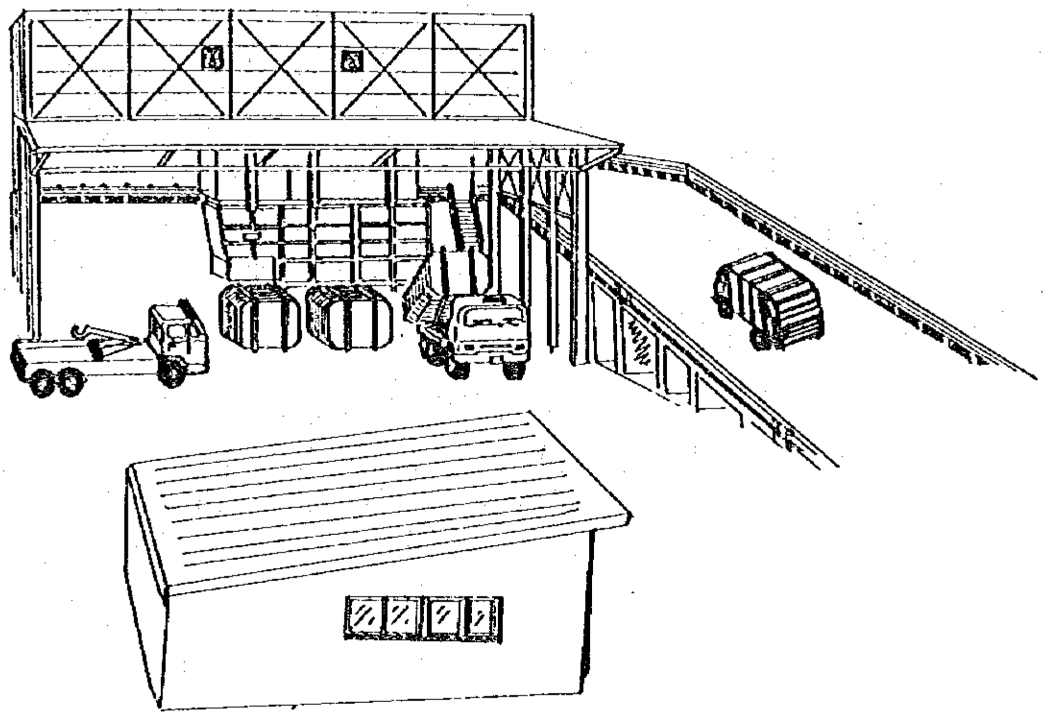
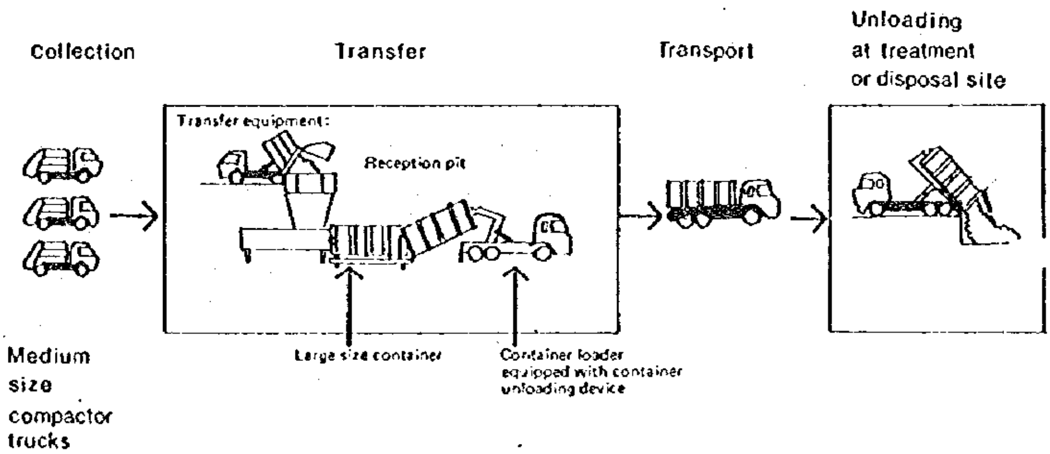


Fig. AP 4.5 Collection and transport using transfer method



Appendix 4.4 Collection work model of a compactor

(1) Formulation of a model of collection and transport work using a compactor

Collection and transport work is composed of the four work components of collection, transport, unloading, and off-route time. Therefore, the total working time per day per crew can be represented by the equation below:

$$T = Tc + Th + Td + T\bar{o} \qquad \text{(Eq. 1)}$$

where, T : a total working time per day per crew

Tc : collection time

Th : transport time

Td : unloading time at destinations

$T\bar{o}$: off-route time (i.e. rest, meals, and other non-productive activities)

The total working time means the daily working time of a crew as stipulated by the office regulations.

Off-route time is the time spent for non-collection purposes such as lunch, breaks, vehicle maintenance, vehicle washing, routine reporting to the office, trips from garage to collection area, and any other purposes which do not immediately relate to collection and transport work.

Collection time includes the time for loading of discharged waste onto a collection truck and travelling from one collection point to the next. Therefore, the collection time is defined with an equation below.

$$Tc = T_1 + Tm = 16.7 \cdot Q \cdot E_1 + Q \cdot Em \qquad \text{(Eq. 2)}$$

where, Q : collection volume (t/d)

T_1 : loading time (min)

E_1 : loading efficiency (s/kg)

Tm : time between transport points (time from leaving one collection point till arriving at the next).

Em : coefficient of moving (min/t)

Loading efficiency is the value obtained by dividing loading time by solid waste weight and expressed as below.

$$El = 60T_1/(1000Q) = T_1/16.7\ Q \qquad \text{(Eq. 3)}$$

Loading time is the total time from arrival of a collection truck at each collection point till departure after completion of loading.

It includes pick-up time together with net loading time.
The coefficient of moving is defined by the following equation:

$$Em = Tm/Q \qquad \text{(Eq. 4)}$$

Transport time is expressible with number of trips per day and transport time per round trip to the destination as below.

$$Th = H \cdot t_h \qquad \text{(Eq. 5)}$$

where, Th : transport time

H : number of trips per day

t_h : transport time per round trip to the destination

One collection truck hauls solid waste several times a day to a destination (a processing plant, a final disposal site, or a transfer station).

$$H = Q/q = Q/C \cdot \gamma \qquad \text{(Eq. 6)}$$

where, H : number of trips (times/d)

q : loading volume per trip (t/trip)

C : collection truck's carrying capacity (m^3)

γ : load density (t/m^3)

$$\gamma = q/C \qquad \text{(Eq. 7)}$$

Accordingly, transport time (Th) is expressed with the equation below.

$$Th = \frac{Q}{C\gamma} \cdot t_h \qquad \text{(Eq. 8)}$$

Unloading time is the time needed for unloading of solid waste from a collection truck at a processing or disposal site, including in-site travel time, the weighing time and waiting time. Unloading time per trip (td) (min / trip) is expressed with the equation below.

$$Td = H \cdot t_d = \frac{Q \cdot t_d}{C \cdot \gamma} \qquad \text{(Eq. 9)}$$

Solid waste collection volume per day per crew is obtainable by inserting the values from the above equations 2 , 8 and 9 into Eq. 1 with the following results:

$$Q = \frac{C \cdot \gamma \cdot (T - \bar{To})}{C \cdot \gamma(16.7E_1 + Em) + (t_h + t_d)} = \frac{q \cdot Te}{q(16.7E_1 + Em) + (t_h + t_d)}$$

(Eq. 10)

Te in the above equation is called effective working time which means net working time, namely, $Te = T - \bar{To}$.

(2) Value of the variables in the model equation

In order to determine value of each variable in Eq. 10, time-and-motion study and the related field surveys were performed. The results are shown in Table AP 4.1. Based on these results, the model of collection and transport work in the year 2000 was established by substituting the following values for the variables in Eq. 10.

Table AP 4.1 Results of time-motion study

		Mean	Min.	Max.	S.D.	No. of samples
Total working time (min)		539	206	960	157	145
Unloading time (min)		8.4	1.0	100.0	10.4	308
Off-route time (min)		52.3	2.0	277.0	48.0	139
Time from a garage to a collection area (min)		20.5	1.0	119.0	19.3	137
Loading efficiency (s/kg)	$6m^3$ N-C	3.46	0.82	25.80	4.64	27
	$8m^3$ N-C	2.90	0.50	18.80	2.11	99
	Compactor	2.01	0.33	5.20	0.97	180

Note: Off-route time doesn't include the time from garage to the collection area.

a. Total working time (T) 540 min

b. Effective working time (Te) 420 min

c. Loading efficiency (E_1) 2.0 s/kg

d. Coefficient of moving (Em)

Coefficient of moving is a parameter governed by factors of collected waste volume, road conditions and traffic conditions, therefore, its value varies per district and area.

As shown on Fig. AP 4.6, the coefficient of moving varies with solid waste volume per collection site.

Solid waste volume per collection site depends on distribution of solid waste generation, number of collection points, and collection frequency. If these factors are almost same in all districts, solid waste volume per collection site can be expressed in relation to collection volume per unit area. Fig. AP 4.7 shows the relation derived from the results of the Field Investigation. Accordingly, coefficient of moving can be estimated based on waste generation volume per unit area, as shown in Table AP 4.2.

Fig. AP 4.6 Relation between coefficient of moving and volume at a collection site

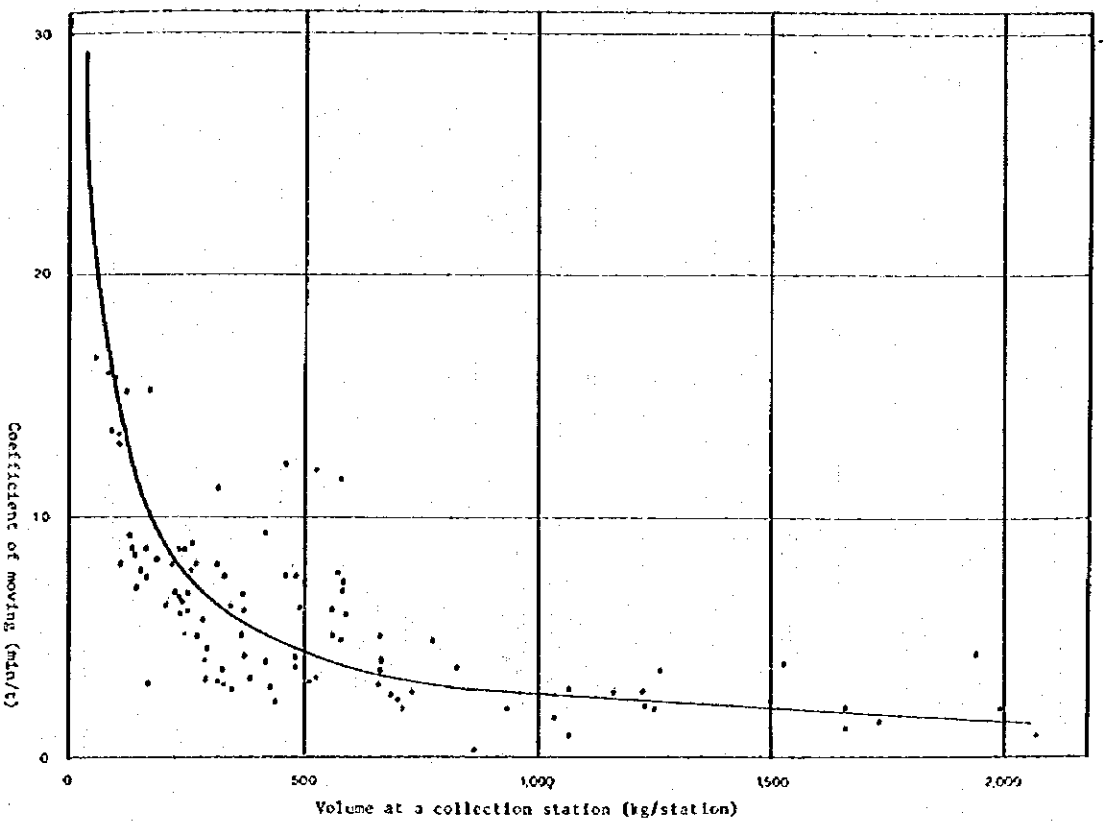


Fig. AP 4.7 Relation between solid waste volume per area and volume at a collection site

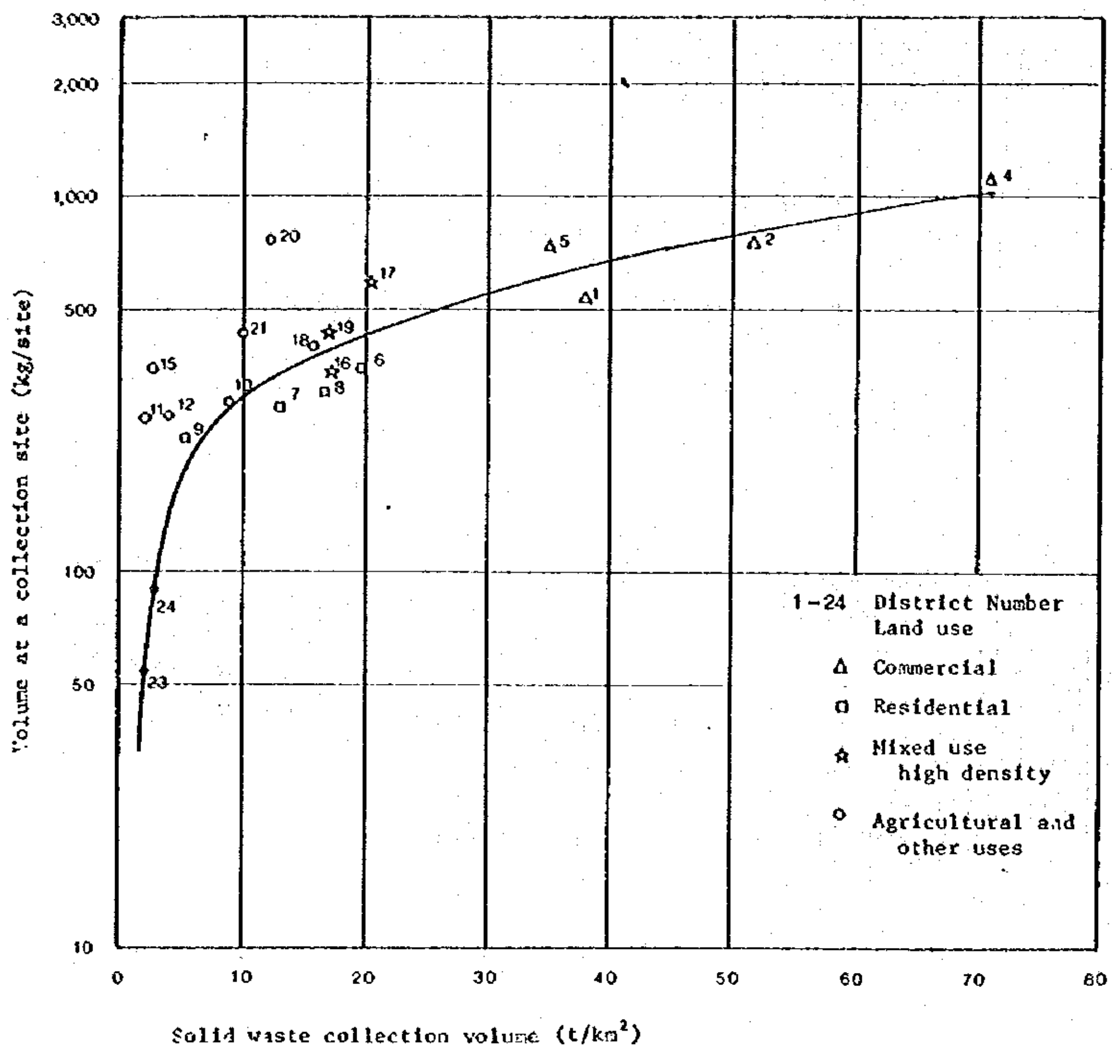


Table AP 4.2 <u>Coefficient of moving</u>

Solid wast generation volume per unit area ($t/km^2 \cdot d$)	Coefficient of moving (Em) (min/t)
30 ∿	4
15 ∿ 30	7
5 ∿ 15	10
0 ∿ 5	15

e. Transport time per round trip (th)

From the results of the field survey, the relation between transport time and transport mileage was obtained as below.

$$th = 4.48L - 3.58$$

where, th: transport time needed for one round trip between collection area and a destination (min/trip)

L : mileage of one way transport (km)

f. Unloading time (td)

Average unloading time was 8 minutes in the field survey; this didn't vary with vehicle type.

Giving some allowance, the standard unloading time was set as 10 minutes.

(3) Determination of collection work model equation

Applying these figures to Eq. 10, the collection volume per vehicle per day (Q) was obtained as in the following equation.

$$Q = \frac{945}{81.57 + Em + 4.48L} \qquad \text{(Eq. 11)}$$

Appendix 4.5 Collection and transport cost

(1) Computation model for estimation of collection and transport cost

Collection and transport cost per day per collection truck is expressed with the equation below.

C(Total cost) = M·H·L (operation and maintenance cost) + F·R·H·L (petrol cost) + y/D(vehicle depreciation) + S(personnel expenses) (Eq. 1)

Collection and transport cost per ton-kilometer is obtainable by dividing the above equation by a total vehicle ton-kilometers. Hence,

$$C_{unit} = \frac{M}{q} + \frac{F \cdot R}{q} + \frac{V}{H \cdot L \cdot q\ D} + \frac{S}{H \cdot L \cdot q} \qquad \text{(Eq. 2)}$$

Where; M :	vehicle operation and maintenance cost	(Baht/km)
F :	fuel unit price	(Baht/L)
R :	fuel consumption volume	(L/km)
y :	vehicle purhcase cost	(Baht/vehicle)
S :	personnel expenses of the workers	(Baht/d)
H :	number of trip by a collection truck	(times/d.vehicle)
L :	Mileage per trip	(km/trip)
D :	term of vehicle depreciation	(d)
q :	solid waste collection volume per trip	(t/trip)
C unit:	cost per ton per km	(Baht/t·km)

(2) Assumptions of the computation model

i) Collection truck operation and maintenance cost: M (Baht/km)

This cost item contains expenses for engine oil, tires and spare parts and wages of workshop mechanics as a repair cost. In the Study, however, the operation and maintenance cost was calculated on the basis of the 1979 fiscal year budget of Mechanical Division, BOF, and the grand total mileage of collection trucks in the same fiscal year, since data concerning the above mentioned expenses were not obtainable. As a result, operation and maintenance cost of collection truck was estimated as 1.25 Baht per kilometer. This unit cost was assumed to remain unchanged for the year 1980.

ii) Fuel consumption volume: R(L/km) and fuel unit price: F(Baht/L)

The average petrol consumption of 7.5 m^3-compactors running in Bangkok city is 2.5 km/L, or 0.4 L/km.

The unit price (retail price) of diesel fuel in Bangkok city in the year 1980 was 6.4 Baht/L.

These figures were taken as the value of R and F and applied to the computation model.

iii) Collection truck purchase cost: v (Baht/vehicle)

7.5 m^3-compactors were assumed to be used also in the year 2000.

Accordingly, the sales price 622,900 Baht/vehicle in the year 1980 was applied to the model.

iv) Personnel expenses of the workers: S(Baht/d)

On the basis of the actual salary scale in force in BMA, the wages were assumed to be 100 Baht/d for each collection truck driver and 80 Baht/d for each collection worker.

v) Number of trips by a collection truck: H(times/d·vehicle)

The number was calculated from the model equations formulated in Appendix 4.4 with the estimated value of collection efficiency of each zone and distance between each zone and the planned treatment or disposal site.

vi) Mileage per trip: L(km/trip)

Mileage per trip was assumed as a sum of transport mileage per trip and travelling mileage in the collection zone per trip. As to the transport mileage, the shortest route from each collection zone to the treatment or disposal site was searched using a computer on the planned road network map of Bangkok city of the year 2000.

The travelling mileage was obtained from the results of the time-and-motion study.

vii) Term of vehicle depreciation: D(d)

The depreciation term of 13 years was cited from "Standardization of Vehicle Operating Cost for Thailand" by the Ministry of Communications, Thailand.

(3) Determination of the model formula

Substituting the above assumptions for the corresponding terms of the formulated model equation (Eq. 2), the following formula was established as the basis for calculating the collection and transportation cost of each appropriate Master Plan alternative.

$$C_{unit} = 1.32 + 190/(HL) \text{ (Baht/t·km)} \qquad \text{(Eq. 3)}$$

Appendix 4.6 Incineration

(1) Significance and characteristics of solid waste incineration

Solid waste treatment by incineration involves converting solid waste into gas and volume-reduced stable solid residue through a process of oxidation (combustion) of combustibles in solid waste.

Urban solid waste is mostly composed of combustibles, therefore, it can be reduced to one-tenths of its original volume by incineration. This is an influential factor in selecting the final disposal subsystem Because of its volume-reducibility and residue-stability, incineration is widely applied to combustible solid waste treatment.

A problem with incineration is the cost for incineration plant construction and operation. An increase of plastic content in solid waste has necessitated incineration plants being equipped with expensive anti-pollution equipment, which also have high operating costs.

(2) Types of incinerator

Physical and chemical nature of solid waste (shape, composition, calorific value, combustibility, etc.) are not stable; they vary in wide ranges. Therefore incinerators are required to have flexibility and adaptability to the varied nature of solid waste.

In selection of an incineration system, evaluation of the system shall be made not only from theoretical viewpoints, but also from practical aspects.

The following types of incinerators are typically in use:

. Grate firing furnace

. Fluidized bed firing furnace

. Rotary kiln

In general, grate firing furnace is the most excellent in performance and, accordingly, most popular.

(3) Continuous-firing furnace

In terms of difference of operation, incinerators are classified into two types as shown below.

Table AP 4.3 Type of incinerator

Batch firing furnace	. Solid waste is fed to furnace at regular intervals and incinerated . This method suits small furnaces
Continuous firing furnace (or mechanical furnace)	. Solid waste is continuously fed to the furnace and incinerated . This method suits large furnace

The continuous firing furnace was developed in order to raise incineration efficiency by means of continuous solid waste incineration. A specific feature of this furnace is its capability of controlling stoker-travel speed and combustion air volume by mechanical means. Therefore, the furnace is kept at nearly constant temperature between 700 and 900°C. This high temperature facilitates minimal generation of pollutants, stabilized generation of exhaust smoke and discharged water, and may contribute to simplifying design of pollution-preventive facilities.

Resource recovery by utilization of incineration heat is also realizable with continuous firing furnace. For this purpose, a boiler and turbine is attached to the furnace to recover energy in the form of steam, hot water or electricity.

Appendix 4.7 Composting technology

(1) Significance of compost application and quality of compost

The purpose of organic material restoration into soil is to help to create a heterogeneous system to store solar energy in soil and to form a well-balanced echological system. Composting is now being reconsidered in various places from both view points of intermediate treatment of municipal solid waste and reutilization of the organic component of municipal solid waste.

The three fertilizing components of compost are N, P and K. Compared with domestic manure, P is abundant but K is scanty. One of the characteristics of city compost is that it contains a lot of Ca. It is expected that completely matured compost products have an effect as a fertilizer ranking next to domestic manure.

As minor elements contained in city compost are greatly affected by composition of municipal solid waste, it is necessary to introduce the classification process in order to minimize mixture of heavy metals. Since the city compost is entirely different in nature from domestic manure which is solely composed of the remains of animals and plants, however, it is necessary to exactly evaluate the significance of compost as a means of organic material restoration into soil.

(2) Composting treatment methods

There are three main composting treatment methods; windrow composting, aerated composting and high rate composting. Windrow composting, the simplest method, has difficulties with prevention of rank odour diffusion and with acquisition of wide area. High rate composting is advantageous in these points as the composting plant is equipped with forcible ventilation equipment and does not require the wide area as windrow composting does. Consequently, high rate composting has become the leading method. In Mexico City which is said to be the greatest in the world for composting treatment, they adopt the windrow composting method based on complete manual classification process and are manufacturing excellent products.

The essential points of compost treating plant lie in the process in fermentation equipment and the process in classifying equipment. The fermentation equipment is divided into the categories of rotary kiln system, vertical multistage system and intermediary of these two systems, according to a type of fermentation tank. However, all of these systems are practically the same. A principal point of compost plant is to allow satisfactory activities of aerobic bacteria. When the performance of classification equipment is increased, on the other hand, the yield of products is apt to be decreased though the quality of compost is improved. In any case, however, the plant construction expenses tend to increase every year due to improvement of plant functions to cope with qualitative diversification of municipal solid waste and satisfy the user's requirements for the product quality.

(3) Fundamental conditions of composting treatment

1) Municipal solid waste as composting material

The solid waste suitable for composting is desirable to be mainly composed of materials which are easily decomposed to small pieces under the primary fermentation. Generally speaking, composition of solid waste differs depending on the collection system. In order to produce good quality products, however, organic-rich materials are desirable.

Materials for fermentation are usually humidified to obtain suitable moisture content for fermentation. On the other hand, in the case of excessive moisture content, the solid waste should be dehydrated.

ii) Classification and pulverization

Classification is carried on before or after fermentation process. However, it is advantageous to classify unsuitable materials before fermentation process from the aspect of equipment efficiency, putting aside the aspects of sanitation and working environment.

A method of classification is affected when pulverization of solid waste is involved. It should be noted that selection of materials for composting is important because mechanical separation cannot achieve the complet removal of unsuitable materials at the present level of technique and the improvement of separation effect involves the increase of equipment cost.

When the adoption of handsorting is determined depending on collection system and composition of solid waste, it greatly improves the product quality. Pulverization is usefull for promoting aerobic decomposition condition but it increases the heavy metal content in some case.

iii) Influential factors to the composting treatment process

a. Moisture content

Moisture content is an influential factor to fermentation temperature. Suitable moisture content of solid waste for fermentation depends on composition of solid waste. Moisture content and oxygen content are in iverse relation; when moisture content is excessive, oxygen becomes short so that compost material becomes unable to maintain an aerobic condition, producing rank odour.

Generally, suitable moisture content for fermentation is in a range of 40 to 60%. When it drops to 30% or less, the decomposition function of compost material (solid waste) ceases.

Content of materials which cannot be decomposed and ferment to compost should not exceed 50% (on dry weight basis) at the moisture content of 60%.

b. Oxygen

Aerobic decomposition produces about 8 kcal of heat value per gram of decomposed carbon which contributes to a rise of compost material temperature to 50 to 70°C. When air is excessive, on the other hand, heat loss is caused.

c. Temperature

Temperature is, as in the case of a chemical reaction, an important factor to control the speed of biological reactions, An external factor such as climate influences compost material to a depth of 20 cm from its external surface so that decomposition of compost material is active in the hot season. Proper turn-over of compost material is effective to heal the shortage of oxygen and increase its temperature.

In general, primary fermentation progresses in a temperature range of 60 to 70°C for possitively decomposable materials which decompose in a relatively short time. In the secondary fermentation, fabric materials or cellulose are converted into lower molecular materials in the secondary fermentation on around 50°C.

d. Carbon-Nitrogen ratio

Composting treatment makes use of a biological reaction, therefore, the ratio between carbon, as an energy source, and nitrogen, as a nourishing source for forming protoplasm, has significant relation with compost quality. C/N ratio of municipal solid waste varies greatly from 40 to 80 depending on the ratio of paper and cellulose contained in the solid waste. C/N ratio decreases to 20 to 30 as ferment progresses. C/N ratio of well-fermented compost is 20 or less.

(4) Concept of restriction of hazardous substance contained in compost

The solid waste compost has problem of hazardous substance contained in the solid waste, being different from compost made from the remains of plants and animals. Therefore, it is absolutely necessary to thoroughly examine and prove the safety and effect from use of these fertilizers from both viewpoints of immediate influence to growth of crops and of influences to farmland soil.

It is also important to examine whether or not the soild waste compost which contains more minor elements such as Cu and Zn, including main components such as N, P and K and also hazardous heavy metals, can produce crops having good market values as in the case of conventional compost.

Therefore, restriction of hazardous substance in solid waste compost should be determined from a viewpoint of fertilizer science.

When compost or sewerage sludge is applied to farm soil, the heavy metal contents in soil increase as the applied volume of compost or sewerage sludge increases (see Table AP 4.4).

Table AP 4.4 Heavy metal contents in soil to which compost and sewerage sludge were applied

Treatment	Zn-applied (ppm)	Soil pH	Element in soil exudated by 0.5M HCl (ppm)							
			Zn	Cu	Fe	Mn	Cr	Pb	Ni	Cd
No treatment	0	4.9	4	3	154	100	0.2	10	1.1	0.5
$ZnSO_4$	40	4.9	28	3	153	111	0.3	7	1.3	0.4
	80	4.9	51	2	161	103	0.4	7	1.9	0.5
	160	4.9	106	3	141	90	0.2	11	1.3	0.8
Compost	40	5.7	32	9	247	147	0.9	23	1.3	0.6
	80	5.7	47	15	285	191	1.5	41	2.1	1.0
	160	6.3	80	18	360	203	3.0	49	2.1	1.7
Sewerage Sludge	40	5.3	29	10	258	222	1.2	28	1.8	2.5
	80	5.3	53	19	363	213	2.0	57	1.4	2.8
	160	5.6	93	27	513	229	5.3	79	2.1	2.9
Compost	analyzed value		1610	340	13310	400	5000	450	300	15
Sewerage Sludge	analyzed value		1810	910	3520	250	520	1570	290	50

Source : 'Compound fertilizer' No. 29, 79-89 (1978)

Adequate applying volume of fertilizer is determined based on the nitrogen contents in many cases. In the case of compost, however, it is necessary to take into consideration minor elements contained in compost. It will be difficult to place restrictions against all these heavy metals. Zn which is contained in a large volume in compost, has weak toxity on animals. Therefore, it is not necessary to be too nervous about its absorption in plants.

On the contrary, Pb and Cr show the toxity on animals but do not appear as harm on plants because a small volume of these metals is absorbed in plants.

Cd and Hg have strong toxity on animals. Therefore, it is absolutely necessary to pay serious attention to absorption of these metals in plants.

Each country places different restrictions on concentration of these heavy metals. Recently, the concept of restrictions against total volume of heavy metals has been adopted in Great Britain and USA from a standpoint of soil protection. Table AP 4.5 shows the guidelines in Great Britain for control of heavy metals, which is worthy of consideration. In controls the total volume of 10 elements which can be applied for the period of 30 years or longer, and it also specifies the maximum yearly applying volume of B and soluble N. Concerning Zn, Cu and Ni, it is based on the concept that the coexistance of these metals should be controlled by added value of hazardous factors of individual metals, and it specifies that Zn-equivalent volume which is obtained by multiplying respective values by individual factors set according to degree of harm to soil, should not exceed 560 kg/ha.

Table AP 4.5 Guidline for application of sewerage sludge to farmland in England (Dept. of the Environment and National Water Council (1977))

Element	Normal Value		Limit of Application in Sludge kg/ha	Applicable Period Year
	Soil mg/kg*	Liquidized Digestion Sludge mg/kg*		
Zn	10-300	1500-3000	560**	30 and longer
Cu	2-100	600-800	280**	-do-
Ni	5-500	50-80	70**	-do-
Cr	5-500	100-400	1000	-do-
Cd	0.1-1.0	7-50	5	-do-
Pb	2-200	200-700	1000	-do-
Hg	0.01-0.3	3-5	2	-do-
No	2	5	5	-do-
As	0.1-40	7.5	10	-do-
Se	0.2-0.5	5	5	-do-
B	2-100	50	Grassland The first year 7	Every year
			The second year onwards 4.5	Every year
			Agricultural land The first year 5	Every year
			The second year onwards 3.5	Every year
Soluble N		From 20,000 to 50,000	Grassland 525 ***	Every year
			Agricultural land: Separately advised ***	Every year

Note: * On dry basis.

** When coexisting, Zn-equivalence is used. Grassland, limy soil. For soil retaining pH 7.0 or higher, the volume can be increased to double.

*** If no danger of nitrogen contamination of surface water and ground water is confirmed, the application volume could be increased 1.5 times as much as the specified figures.

Appendix 4.8 Basic conditions for formulation of an intermediate treatment system

Alternatives of intermediate treatment system is established according to the procedure shown in Fig. 4.2 of the Final Report.

(1) Volume and composition of solid waste to be intermediately treated.

i) Solid waste generated in Bangkok city is presently collected by the Garbage Collection Division, BOS, which also collects a part of market waste and a part of hospital waste, and by the Sanitary sections of the districts which collect the other business waste and household waste without distinguishing between these two kinds of wastes.

An examination was made from the viewpoint of intermediate treatment of whether or not solid waste should be discharged as classified by the dischargers themselves, and it was concluded that, a rule, classified solid waste discharge would not need to be done. As for market waste and hospital waste, however, a separate collection system was recommended since market waste is suitable for composting and hospital waste is hazardous.

Physical and chemical characteristics of solid waste vary by generation source (refer to Chapter 2).

Solid waste sampled from the reception pit of the existing compost plant shows the typical character of solid waste generated in Bangkok city as a mixture of miscellaneous waste from various sources. For framing of an intermediate treatment subsystem in the Master Plan, the reception pit waste was taken as typical of the waste of Bangkok city and, based on its composition analysis, the future composition of the typical waste was forecast in the preceding chapter. (2.3 Forecast of the future solid waste composition)

Applicability of each intermediate treatment method to solid waste composition which varied with generation source was examined and the results are briefly described below.

a. Household waste

Judging from the paper/garbage ratio, moisture content and C/N ratio, household waste seems suitable for composting, providing classification preliminary treatment is thoroughly made, since household waste contains a considerable volume of unsuitable materials for composting such as plastics, incombustibles, and poisonous materials such as fluorescent lamps and dry batteries.

The lower calorific value of household waste is approximately 1,100 kcal/kg, which is sufficient for self-combustion; however, when household waste contains superfluous water content caused by rainwater, for instance, auxiliary fuel may be required for combustion.

b. Market waste

A large part of market waste consists of garbage and plants which are the most suitable components for composting.

As market waste has high moisture content, it is not be advantageous to incinerate market waste alone.

c. Large-store waste, hotel waste, and office waste

Although these wastes have lower calorific values, the values are sufficient for incineration. However, less garbage and plant content makes these wastes disadvantageous for composting.

Large-store waste and office waste contain large volumes of paper; therefore, paper recovery by commercial retrieval can be encouraged.

d. Factory waste

Factories have a tendency to discharge different types of waste from different types of factories. In many cases, commercial retrievers collect each sort of factory waste separately. This collection system is recommended to be continued.

In the case of mixed factory waste, incineration will be a suitable treatment method if the generated volume is small.

e. Reception pit waste

It seems reasonable to send reception pit waste for composting treatment since it contains a considerable volume of garbage and plants. For better compost, it is advisable to accept only market waste and household waste incoming to reception pit.

The calorific value of reception pit waste (approx. 1,130 kcal/kg) is near the lower limit for self-combustion, therefore, auxiliary fuel may be required for the incineration during rainy seasons or rainy days. If the more stable and sure incineration is required, then market waste must be eliminated from reception pit waste.

ii) Volume

The forecast solid waste generation volume is given in the Table 2.13.

Aiming at "total volume collection and disposal" which is one of the goals of the project, all the collected solid waste is planned to be either intermediately treated or disposed of with sanitary landfill. Accordingly, solid waste volume to be intermediately treated is a large part or perhaps the total collected volume. In the case of the total volume coming from intermediate treatment, the most influential factors to its management are fluctuation of solid waste generation volume and operation rate of the treatment plant.

a. Fluctuation of solid waste generation volume

The fluctuation by days and by months are described in the preceding chapter. (ref. Appendix 2.9)

Incoming solid waste volume to an intermediate treatment plant is conspicuously large in the initial part of a week (particularly on Mondays). To cope with this fluctuation, the reception pit is designed to store three times as much solid waste as can be daily treated by the plant. Therefore, the capacity of the intermediate treatment plant may be planned equal to the average incoming waste volume per day, since the daily fluctuation is cushioned by reception pit and does not affect capacity. Nevertheless, unless plant capacity is planned to meet monthly fluctuations it will be insufficient to cope with them. Accordingly, when total volume intermediate treatment is intended, the plant capacity should be increased by about ten percent above the daily average incoming volume in order to cope with monthly fluctuation. In case direct landfill as well as intermediate treatment is planned, consideration of the monthly fluctuation is not always necessary for determination of the intermediate treatment plant capacity.

b. The plant operation rate

Intermediate treatment facilities will stop operation because of breakdown, inspection or repair.

Normally, the period of the plant operation stoppage is 10 to 20 percent of a year. In the other words, the average annual treatment capacity is calculable by multiplying the plant capacity by an operation rate somewhere between 0.8 and 0.9. Thus, the total capacity of treatment facilities in the case of total volume intermediate treatment is estimated to be 10 to 20 percent larger than the daily average incoming waste volume considering the daily and monthly fluctuation.

(2) Policies for intermediate treatment

Taking the circumstances of Bangkok city into account, the aforementioned purposes of intermediate treatment were modified into the following four policies, based on which, intermediate treatment should be conducted.

a. Top priority should be given to making solid waste non-toxic and harmless.

b. Resource recovery from solid waste should be promoted.

Resource recovery is very important since it contributes not only to natural resource savings but also environmental protection and landfill space savings. For effective promotion of resource recovery, policies of efficient resources utilization and minimal energy consumption by intermediate treatment facilities themselves have to be pursued.

c. To prevent pollution caused by intermediate treatment, the Factory Act and the other anti-pollution-related laws and regulation should be observed.

d. Existing composting treatment should be respected.

The fact that BMA has been operating composting plants must be respected. Therefore, in framing the intermediate treatment sybsystem plan, deliberate consideration will be made of this fact and utilization of the existing compost plants.

(3) The prospect of the future composting treatment in Bangkok, and technical evaluation of the existing intermediate treatment facilities.

Constant demand throughout the year for inorganic fertilizer assures the stable market and production of chemical fertilizer, though its profitability is small. In addition, since the value added to inorganic fertilizer is producible at relatively low cost, fertilizer consumption is stimulated.

On the other hand, demand for compost fluctuates from season to season. To meet this fluctuation, compost plants should have large production facilities to meet the needed production capacity.

Even in West Germany where reutilization of organic materials is most progressed, only one percent of the total solid waste volume is reutilized in agriculture. The state of organic material reutilization in Japan is far behind that in West Germany.

From this point of view, the scale existing compost production plants in Bangkok can be said be large in international terms.

i) Present quality of BMA compost

Tables AP 4.6 to 4.11 show the ripeness, fertilizing value, hazardous materials and their extraction, particle size, and impurities content.

Table AP 4.6 Chemical analysis of Nong Khaem compost (before trommeling)

Parameters		Ave.	Max.	Min.	S.D	CV(%)
Ripeness (Maturity)						
pH		8.36	8.65	8.05	0.246	2.9
EC	μ mho/cm	1,240	1,380	1,130	106	8.5
COD, $KMnO_4$	mg/kg	2,223	3,620	1,560	948	42.7
$K_2Cr_2O_7$	mg/kg	5,220	6,120	4,230	950	18.2
C/N		18.8	24.8	16.4	4.05	21.5
C	%	19.2	19.8	18.4	0.580	3.0
CEC	mg eq/100 g	65.6	76.1	58.3	7.59	13.5
Ignition Loss	%	37.7	41.0	34.4	3.48	9.2
Appearance		-	-	-	-	-
Germination Test	%	100	100	100	0	0
Fertilizing Value						
Moisture Content	%	42.2	49.4	35.5	5.96	14.1
Total-N	%	1.05	1.18	0.77	0.189	18.0
NH_4-N	mg/100 g	24.0	33.5	18.3	6.563	27.3
NO_2-N	mg/100 g	1.15	1.50	0.80	0.311	27.0
NO_3-N	mg/100 g	6.68	10.4	3.8	3.21	48.1
Total-P_2O_5	%	0.84	0.94	0.78	0.070	8.3
Total-K_2O	%	0.84	0.96	0.78	0.0812	9.7
Total-CaO	%	7.59	12.4	4.02	3.69	48.6
Total-MgO	%	0.468	0.74	0.18	0.232	49.6
Cu	mg/100 g	65.25	72.00	58.00	6.397	9.80
Zn	mg/100 g	76.0	166	18	64.52	84.9
Mn	mg/100 g	167.8	207	102	47.58	28.4
Mo	mg/100 g	20.8	31.5	13.3	7.677	37.0
B	mg/100 g	4.37	6.22	3.13	1.515	34.7

Table AP 4.6 (cont'd)

Parameters		Ave.	Max.	Min.	S.D	CV (%)
Hazardous Materials						
Alkyl-Hg	mg/kg	ND	-	-	-	-
Hg	mg/kg	4.28	6.01	3.12	1.34	31.3
Cd	mg/kg	8.51	11.9	5.32	2.69	31.7
Pb	mg/kg	409	879	155	332.1	81.2
- Methyl dimethone						
- Methyl parathione		ND	-	-	-	-
- Parathione, EPN		ND, ND	-	-	-	-
Cr^{6+}	mg/kg	ND	-	-	-	-
As	mg/kg	4.42	9.92	0.16	5.00	113.2
CN	mg/kg	0.938	1.40	0.60	0.335	35.7
PCB	mg/kg	0.403	0.67	ND	0.328	81.5

Note: ND: Not detectable.

Table AP 4.7 Elution test of Nong Khaem compost (before trommeling)

Parameters		Ave.	Max.	Min.	S.D	CV (%)
Hazardous Material						
Alkly - Hg	mg/L	ND	-	-	-	-
Hg	mg/L	0.103	0.18	0.07	0.063	51.2
Cd	mg/L	0.053	0.080	0.030	0.022	42.2
Pb	mg/L	1.00	1.50	0.73	0.350	35.0
Organic phosphorus Comp.,	mg/L					
- Methyl dimethone						
- Methyl parathione		ND	-	-	-	-
- Parathione, EPN		ND, ND	-	-	-	-
Cr^{+6}	mg/L	0.188	0.65	ND	0.312	166
As	mg/L	0.040	0.06	ND	0.028	70.7
CN	mg/L	0.024	0.05	$7x10^{-3}$	0.020	82.4
PCB	mg/L	0.004	$14.1x10^{-3}$	ND	0.007	200

Table AP 4.8 Chemical analysis of Nong Khaem compost (after trommeling)

Parameters		Ave.	Max.	Min.	S.D	CV (%)
Ripeness (Maturity)						
pH		8.26	8.65	7.55	0.497	6.02
EC	μ mho/cm	1,917.5	2,930	1,440	683.4	35.6
COD, $KMnO_4$	mg/kg	2,141	4,260	963	1,478	69.0
$K_2Cr_2O_7$	mg/kg	5,938	8,700	2,820	2,530	42.6
C/N		76.5	256	15.7	119.7	156.4
C	%	20.1	21.5	18.7	1.20	6.0
CEC	mg eq/100 g	55.5	58.1	52.8	2.17	3.9
Ignition Loss	%	40.1	41.9	37.9	1.67	4.2
Appearance		-	-	-	-	-
Germination Test	%	100	100	100	0	0
Fertilizing Value						
Moisture Content	%	34.7	41.8	28.5	5.46	15.7
Total-N	%	0.918	1.32	0.08	0.567	61.8
NH_4-N	mg/100 g	24.3	25.2	23.1	0.885	3.6
NO_2-N	mg/100 g	1.15	1.50	0.9	0.30	26.1
NO_3-N	mg/100 g	5.15	6.3	4.2	0.975	18.9
Total-P_2O_5	%	1.04	1.14	0.9	0.108	10.4
Total-K_2O	%	1.06	1.29	0.81	0.198	18.6
Total-CaO	%	7.74	14.2	3.41	4.60	59.4
Total-MgO	%	0.523	0.86	0.20	0.276	52.9
Cu	mg/100 g	133.2	211	97.0	52.9	39.7
Zn	mg/100 g	90.2	166	12.0	63.2	70.0
Mn	mg/100 g	139	181.0	98.0	38.9	28.0
Mo	mg/100 g	16.8	19.1	13.8	2.49	14.9
B	mg/100 g	6.25	7.25	5.57	0.711	11.4

Table AP 4.8 (cont'd)

Parameters		Ave.	Max.	Min.	S.D	CV (%)
Hazardous Materials						
Alkyl-Hg	mg/kg	ND	-	-	-	-
Hg	mg/kg	3.50	5.32	2.80	1.22	34.9
Cd	mg/kg	14.4	21.1	9.61	4.91	34.2
Pb	mg/kg	359.5	603	242	164.7	45.8
Organic Phosphorus Compound						
- Methyl dimethone						
- Methyl parathione		ND	-	-	-	-
- Parathione, EPN		ND,ND	-	-	-	-
Cr^{+6}	mg/kg	ND	-	-	-	-
As	mg/kg	4.87	7.36	2.52	2.17	44.6
CN	mg/kg	1.11	1.80	0.60	0.504	45.3
PCB	mg/kg	0.433	0.81	0.23	0.258	59.6

Table AP 4.9 Elusion test of Nong Khaem compost (after trommeling)

Parameters		Ave.	Max.	Min.	S.D	CV (%)
Hazardous Material						
Alkly - Hg	mg/L	ND	-	-	-	-
Hg	mg/L	0.050	0.070	0.030	0.018	36.5
Cd	mg/L	0.235	0.75	0.04	0.344	146
Pb	mg/L	0.830	1.25	0.46	0.340	40.9
Organic phosphorus Comp.,	mg/L					
- Methyl dimethone						
- Methyl parathione		ND	-	-	-	-
- Parathione, EPN		ND,ND	-	-	-	-
Cr^{+6}	mg/L	0.10	0.40	ND	0.200	200
As	mg/L	0.013	0.030	ND	0.015	120
CN	mg/L	0.036	0.070	0.002	0.034	97.1
PCB	mg/L	ND	-	-	-	-

Table AP 4.10 Percentage of components under 10 mm in compost

(%)

	Period	On-Nooch compost	Ram Intra compost	Nong Khaem compost*
on wet weight basis	1st	42.7	47.9	22.6
	2nd	16.4	9.4	4.4
	3rd	22.2	31.0	23.3
	4th	34.5	38.9	47.9
	Average	29.0	31.8	24.6
on dry weight basis	1st	44.0	49.3	23.6
	2nd	17.4	11.4	5.1
	3rd	24.3	29.9	24.6
	4th	34.4	38.4	47.6
	Average	30.0	32.3	25.2

Note: * means before trommeling.

Table 4.11 Percentage of impurities in compost

(%)

	Period	On-Nooch compost	Ram Intra compost	Nong Khaem compost	
				(before separation)	(after separation)
on wet weight basis	1st	6.0	5.7	14.4	1.9
	2nd	15.3	11.9	24.7	1.2
	3rd	22.6	21.3	14.0	0.8
	4th	19.5	16.2	15.6	1.0
	Average	15.9	13.8	17.2	1.2
on dry weight basis	1st	9.8	10.6	16.3	2.8
	2nd	19.3	17.5	25.3	1.4
	3rd	26.4	25.7	15.5	1.0
	4th	22.7	19.9	17.4	1.2
	Average	19.6	18.4	18.6	1.6

ii) Compost sales price

The present price of unpacked compost varies from 370 to 740 Baht per ton according to its quality. (Ref. Appendix 3.1, 10, (6)) When considering the marketability of compost, the nature of compost as soil improvement material should be strictly distinguished from fertilizer.

Names and prices of competitive products to city compost in the market are listed in Table AP 4.12. They are all compost products made mainly from buffalo dung. Their prices are equivalent to or a little higher than BMA compost; therefore, BMA compost has a competitive price.

A farmer should, however, pay 75 Baht for the manure of BMA compost in order to get 100 Baht of sales figures on the conditions of the average rice yield of 111 kg per 10 a and the retail sale price of 600 Baht per 100 kg (producer's sale price is much lower than this). This burden is too big for the farmer and it may be concluded that the present price of BMA compost is very high.

Table AP 4.12 Competitive Compost Products

Company Name	Product Name	Size	Wholesale Price (Baht)	Retail Price (Baht)	Composition	Suitable Plants
Wong Sawang Agriculture	Pooy Kork 222	per m^3	400	450	Grinded ox and bat excrements	Trees, Plants
	Pooy Insi 333	per m^3	520	550	Grinded ox and bat excrements, rice hulls, beans, shell	Trees, Plants
Sida Farm	Din	5 kg	3.50	5	-	Trees, Plants
	Ke Wua	5 kg	3.50	5	Ox excrement	Every kind of Plant
Tada Farm	Pooy Kork	15 kg	15	20	Ox excrement and soil	Plants
Chuchu	Pooy Kork Chutham	-	-	-	Dried ox excrement	Trees, Plants
Bangkok Tanakij Co., Ltd.	Keaw Ku	50 kg	280	310	-	Every kind of plant
Rung Watana Agriculture	Hua Wua	50 kg	315	325	Urea, $(NH_4)_2SO_4$	Plants
Rojana Kasikit Ltd. Part.	Pui Kaimuk	per ton	4,500 - 6,500	-		Fruit trees
Economic Chemical	Bat (Ecophos)	50 kg (pellet)	3,400 5,800 4,700 5,500 5,900	- - - -	+21-0-0 46-0-0 26-0-0 15-15-15 15-15-21	Vegeta-bles, all plants
Others		1 L (liquid) 1 kg (Powder)	25 - 5,500	-		

iii) Estimate of potential demand for compost

Soil of the central plain where Bangkok city is located is mainly composed of heavy clay. In general, application of organic material to clayey farmland is believed effective.

Composting to paddy field which comprises more than 70% of total farmland in Thailand is, however, not always thought to be practical or effective. Weak results of composting to paddy field in many countries and the fact that compost contains considerable alien materials all imply the passivity of compost application to paddy field. As a matter of fact, the results of questionnaire research indicate that practical use of compost in Thailand is mostly to fruit trees, garden flowers and vegetables. This exclusive use of compost will grow as diversification of agricultural activities progresses (ref. Table AP 4.13). Thus, all observations indicate that endeavors for compost market development should be directed to actualize the latest demand of plowed fields and orchards. Although potential demand for compost throughout Thailand is believed huge, it is not practical or possible to estimate all latent demand in Thailand. Based on the burden of compost transport cost, plowed fields within a 50-km radius from Bangkok (588,000 rai) were considered, and potential demand for compost with them was estimated (ref. Fig. AP 4.8). As a result, 940,800 tons per year was estimated as the annual maximum compost demand, assuming 1 ton per 10 are of compost use per annum.

According to the questionnaire survey about use of city compost made in 1980 (ref. Table AP 4.14), those who wished to use compost were 17% of the total. From this result, potential demand for city compost is estimated to be 10% of all plowed fields. This totals approximately 90,000 tons per year, which is equivalent to about 1,900 t/d of compost plant capacity. Since the existing compost plants have a total capacity 1,120 t/d, several additional plants with an approximate total capacity of 800 t/d could possible be constructed.

Table AP 4.14 Results of the survey of the intention of compost use

	Will definitely Use BMA Compost	Not Want to Use BMA Compost	Might Use BMA Compost		
			Use BMA Compost Now	Used BMA Compost Before	Use Other Products Now
No.	11	7	7	10	7
%	17	11	11	16	11

	Satisfied with other Products	No Comments	Total
No.	17	5	64
%	26	8	100

Source: Field Investigation Report, JICA, Jan. 1981

Table AP 4.13 Agricultural land-use

i) Change of agricultural land use

(unit: x 1,000 rai)

	The whole area of Thailand	The state forest area	Farmer-owned					
			Total	Paddy field	Plowed farm	Orch-ard	For-est	Housing land and others
1950(A)	319,960	173,188	55,697	37,375	5,039	5,769	5,366	2,148
1960(B)	321,250	167,218	61,683	38,127	6,906	6,145	5,336	5,169
1975(C)	321,250	131,663	116,282	73,226	21,507	11,395	4,743	5,411
Growth (C)/(B)	1.00	0.79	1.89	1.92	3.11	1.85	0.89	1.05

ii) Transition of planting acreage

(unit: x 1,000 rai)

	Rice	Cassava	Sugar cane	Maize	Kenaf	Green peas
1960/61(A)	37,012	447	986	1,785	877	327
1977/78(B)	53,465	6,000	3,541	7,534	1,603	2,720
Growth (B)/(A)	1.44	13.42	3.59	4.22	1.83	8.32

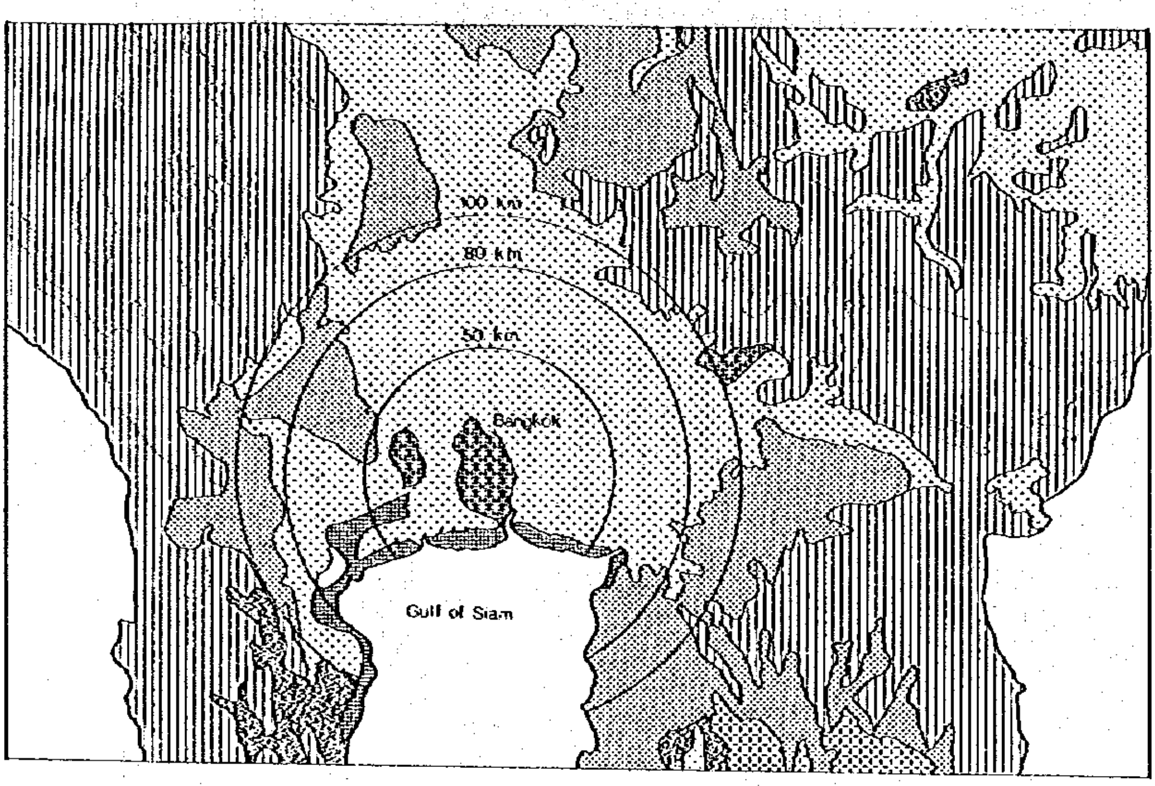
iii) Progress of rough rice production by regions

Region	Year 1956/57 (A)		Year 1978/79 (B)		(B)/(A)		Refined rice Crop (kg per 10 a)	
	Area (1,000 rai)	Rice production (1,000 t)	Area ((1,000 rai)	Rice production (1,000 t)	Area	Rice production	Thailand	Japan
North	6,738	2,411	12,901	4,983	1.91	2.07	159	-
North-east	15,517	3,130	26,654	5,148	1.71	1.64	79	-
Central	12,535	3,606	13,566	4,149	1.08	1.15	126	-
South	2,858	792	3,868	1,133	1.35	1.43	121	-
Whole Thailand	37,648	9,939	56,989	15,413	1.51	1.55	111	482

Source: Statistics of Agricultural Cooperative Association

Note : Production volume in 1978/79 does not contain the secondary crop (approx. 2 million tons).

Fig. AP 4.8 Land use in and around Bangkok



Legend:

- Paddy field
- Orchard
- Orchard + Rubber , Rubber
- Forest , Field crop + Forest (70 - 30%)
- Corn , Sugar corn , Cassava
- Salt pan , Shrimp and Fish pond
- Others ···· Paddy field + Field crop (50 - 50%) , Fiber crop , Banana , Pineapple , Other fruits

Source : Land Use Plan Department of Land Development

iv) Development of compost market

Needless to say, the most essential point to develop the market for compost is qualitative improvement of the compost. In Northeast Thailand, improvement of soil by composting organic materials is required. If compost transport and storage measures are arranged with the cooperation of the concerned local administrations, it could be possible to develop a large compost market in Northeast Thailand.

Compost is used not only as soil improving material, but also as much to prevent evaporation of moisture from farm soil.

From this aspect also, new markets for compost should be developed.

a. Utilization of compost for other purpose

As a secondary use of compost, application of compost landfilling and agricultural land reclaiming will be effective.

b. Influential factors upon compost distribution

Characters of compost which may influence on its distribution are as follows:

- Volume
- Large moisture content and high hygroscopicity
- Compost demand fluctuates seasonally, therefore, stable production and supply throughout the year are not expectable
- Compost prices are too high compared with prices of agricultural products to which compost is applied
- Transport to remote places is too costly
- Storage facilities are required nearby the consumers

Accordingly, when compost distribution is considered, the following points should be taken into account:

- From the transport point of view, the distribution should be limited to an area within a 100-km radius from Bangkok.
- To supply reliable compost quality, quality control should be made on the distribution process.
- For convenience of the transportation and handling, packing the compost is preferred. In the case of unpacked compost transport, adoption of special compost-carrying trucks is desirable.
- For composting on farmlands, mechanical or cattle distribution means should be applied.

v) Technical evaluation of the existing compost plants

Among numerous and miscellaneous problems with the existing compost plants, some of the more significant ones are considered below.

a. Composting facilities

The compost currently produced contains a considerable volume of unsuitable materials for compost such as plastics, glass, etc., and small but not negligible volume of toxic heavy metals. This is due to the deteriorated performance of the mechanical classifier with which unsuitable waste for composting is supposed to be rejected. Because of its unsatisfactory quality, the compost produced in On-Nooch and Ram Intra compost plants is not able to be sold, but is simply discarded over landfill sites. Only in Nong Khaem compost plant, secondary fermented compost is sent to additional equipment Trommell for refining and sold in the market.

In the existing compost plant system, only a five-day period is allocated for primary fermentation whereas a two-month or longer period is given for the secondary fermentation in open air.

This means that BOS considers the role of the primary fermentation as not so important. If such short primary fermentation satisfies the required compost quality, the aerated composting system could have been chosen instead of the existing system. The aerated composting system is simplier in structure, lower in production cost, and easier to maintain than the existing system.

b. Incineration facilities attached to compost plants

Unsuitable waste for composting which is rejected by the classifier in the composting process is incinerated in the attached incinerator.

The lower calorific value of rejected unsuitable waste is approximately 1,150 kcal/kg, which is the sufficient value for self-combustion on an average.

An observation was made concerning the combustion of one of the attached incinerators, and the actual incineration capacity was noticed to be much lower than the designed capacity. On account of incomplete combustion in the incinerator, ignition loss (%) of incineration residue seemed high. Although such insufficiency of incineration capacity could be caused by superfluous feeding of combustion air or by any other inadequacy of operation, the fact that installation of air heater had not been considered in the design indicates the cause of the incineration insufficiency is attributable to the poor original design of the incinerator.

c. Compost plant

Inadequate condition of the existing compost plants cause the following pollution:

- Rank odour generated in compost plant and the secondary fermentation yard
- Water pollution caused by leachate from the secondary fermentation yard
- Air pollution caused by exhaust gas from the attached incinerator

No positive means to prevent these types of pollution have been taken so far. It is behaved that the reason why the compost plants can be operated without employing moderate measures against pollution is that their locations were remote from the populated areas so that natural and social environment surrounding them could accpet the pollution. However, owing to rapid urbanization, surroundings of the existing plants will be soon urbanized and, if the plants remain as they are, the nearby inhabitants will eventually protest and plant operation will face difficulties.

vi) Utilization of the existing compost plants in the Master Plan

Although the existing compost plants have drawbacks as mentioned above, they are planned to be organized in the Master Plan and utilized in the future, provided that the following improvements are implemented in addition to those specified items in the short-term improvement plan.

a. Proper operation control

Effective and efficient operation of compost plants according to the operation standard formulated and by controlling pollution.

b. Implementation of proper repair

Proper and periodic overhaul of compost plants should be implemented annually. In addition, thorough repair of the plants will be required at least twice by the year 2000.

c. Acquisition of adjoining site to compost plants and promotion of environmental control

In order to preserve the surrounding environment with the least alteration of the existing compost plants, acquisition of the adjoining sites to compost plants is recommended. This is not only for environmental protection but also for assuring adequate future landfill sites in advance. At the same time, measures to control pollution generation should be attempted by means of, for example, improvement of landfill and management methods.

(4) Evaluation and selection of intermediate treatment methods

i) Evaluation system

An evaluation system as shown in Fig. AP 4.9 was formulated and, according to this, intermediate treatment methods were evaluated and selected. The selected intermediate treatment methods were taken as components composed of the intermediate treatment system alternatives.

ii) Applicability of preliminary treatment methods

Solid waste intermediate treatment process is divided into preliminary treatment (front-end system) and conversion treatment (back-end system)

Although the main function of intermediate treatment is in the conversion process, preliminary treatment has recently been given more importance than ever from the material retrieval point of view. The applicable preliminary treatment methods from this viewpoint are listed in Table AP 4.15.

Considering the adaptability of each preliminary treatment method, applicability of a system which emphasizes preliminary treatment for solid waste disposal in Bangkok was thought to be doubtful.

Therefore, in selection of intermediate treatment methods, adaptable conversion methods for Bangkok city were first selected as the main function of the treatment process, then the most suitable preliminary treatment methods for the conversion methods were chosen.

Fig. AP 4.9 Evaluation system of intermediate treatment methods

1. Environmental factors
   - Intermediate treatment ability
     - Adaptability to solid waste composition
     - Necessity of preliminary treatment
     - Decontaminatability (incl. health maintenance)
     - Stability
     - Volume-reducibility
   - Pollution prevention ability
     - Air pollution prevention ability
     - Water pollution prevention ability
     - Rank odour prevention ability
     - Landscape
2. Natural resource conservation factors
   - Material recoverability
   - Energy recoverability
   - Landfill stability
3. Operational factors
   - Maintainability
     - Operability
     - Repairability
   - Practicality, Reliability
4. Economic factors
   - Construction cost, maintenance cost
     - Operation cost
     - Repair cost
   - Revenue from resource recovery
5. Institutional factors
   - Practicability from political viewpoint
   - Legal system
   - Influence on collection & transportation system
   - Influence on final disposal system

Table AP 4.15 Applicability of preliminary treatment methods

	Method	Recovered Material	Applicability
1	Compression	Landfill material	1. High pressure type compression is examined here. Low pressure type packing system is examined in the study of collection and transportation system. 2. This method has the following weak points, and accordingly, application of this method to Bangkok is unrecommendable. (1) Though transportation efficiency is improved a little, no significant space-saving effect of landfill site is expectable. (The equivalent effect to raw waste being landfilled for 3-5 years is obtainable.) (2) Shortly after completion of landfilling, the reclaimed land could be usable as parks and playgrounds but difficult to be used as construction sites. (3) When compressed, considerable volume of filthy leachate is produced that requires additional leachate treatment. (4) Treatment cost is higher than incineration. (5) A recent tendency is that the number of compression facilities has been decreasing.
2	Classification	Ferrous metal Non-ferrous metal Paper Glass Plastics Others	1. If tremendous volumes of solid waste (approx. 5,500 t/d) forecasted to be generated in Bangkok city in the year 2000 is to be intermediately treated through classification as the main function, adoption of mechanical classifiers will be inevitable. 2. The existing classification equipment is inferior in performance and their classifiability is limited to particular sorts of materials. (Recovered material is so degraded in purity that cannot be sold as it is.) 3. If refining cost of recovered material is added, the total recovery cost often exceeds production cost from raw material resources. 4. If many sorts of materials are to be selected for recovery purpose, several types of classification equipment are required; hence, construction cost of the mechanical classification facilities could reach as much as incineration plant construction cost. 5. Establishment of a recovered materials market is an indispensable condition for material recovery. 6. Usually, half the solid waste remains unselected after selection of reutilizable materials; therefore, disposal system of the remainder should be separately considered. 7. Manual selection, which contributes to the increase in employment, is one of the possibilities. Practically, however, it will not be possible to have many workers engaged in unsanitary work. If it is only a provisional arrangement and does not last long that BOS hires people who are illegally collecting recoverable materials at landfill site and have them engaged in manual classification with intention of improving compost quality (particularly, elimination of heavy metal containing materials) as well as offering them jobs, it will be significant to provide a manual classification stage to the existing facilities.
3	Pulverization + Classification	Refuse derived fuel (RDF) Ferrous metal	1. Pulverized RDF is normally used in the mixed form with coal. 2. The most capable facilities of accepting large volume of RDF and consuming it daily are, as the actual cases show, steam power stations using coal fuel. 3. The existing power stations in Bangkok city are all using heavy oil for energy and no facilities were found which can accept volumes of RDF daily. 4. It is impossible to apply this method to the intermediate treatment system in Bangkok.
4	Pulverization	Landfill material	This method is excluded from examination since this is believed to be a preliminary treatment method for the final disposal system.

iii) Primary evaluation, and selection of conversion methods

Other than the traditional conversion methods of incineration and composting, various new conversion methods have been developed or under development.

Among them, methanation and feeding (conversion to animal feed) were excluded from evaluation and selection, for the following reasons.

a. Methanation

Methanation technology is still under development and practical facilities of urban waste methanation are not in operation yet; therefore, practicability and reliability of methanation method remain unconfirmed.

Methanation facilities are able to cope with organic waste only. For disposal of unsuitable waste for methanation and the treatment residue, additional treatment method is required.

b. Feeding (conversion to animal feed)

Reutilization of solid waste by feeding method is limited to food waste. Usually, this method is utilized by private sectors (stock-breeders and feed-makers).

iv) Secondary evaluation and selection of conversion methods

Through the primary evaluation, four conversion methods (incineration, pyrolysis, slagging pyrolysis and composting) were selected. They were further subjected to secondary evaluation and selection according to the evaluation system (Fig. AP 4.9). The results of the secondary evaluation and selection are displayed in Table AP 4.16. Process flows are shown in Fig. AP 4.9.

As seen in the table, each conversion method naturally has advantages as well as disadvantages. From overall point of view, incineration and composting were judged to be the most reasonable methods to be selected as components of the intermediate treatment system plan.

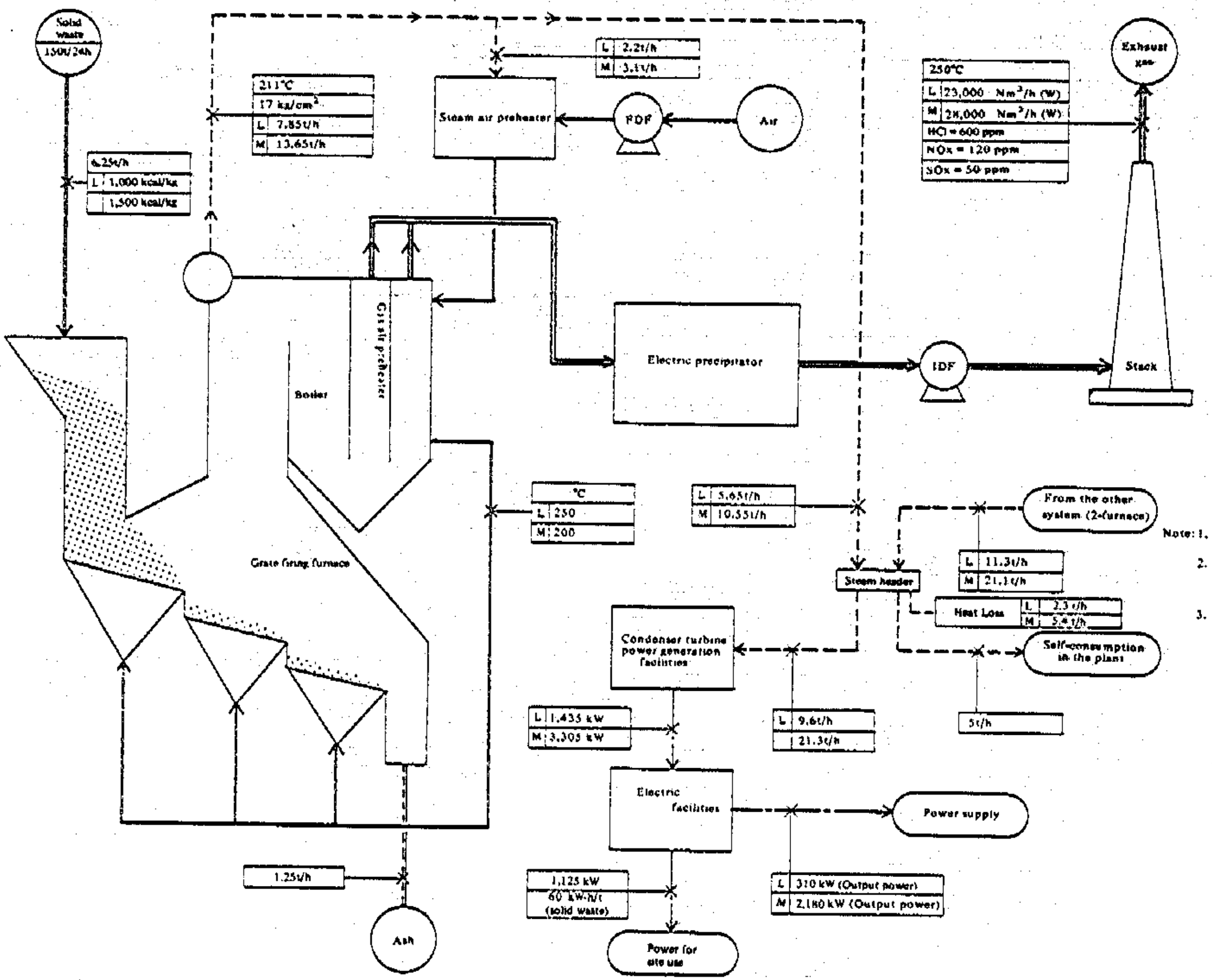
Table AP 4.16 Evaluation of conversion methods

Evaluation item			Incineration (I)		Pyrolysis (P)		Slagging, pyrolysis (S.P)		Composting (CP)
Environ-mental factor	Intermediate treatment ability	A	1. Applicable to a wide range of lower calorific value (Hu) of solid waste from 900 to 3,000 kcal/kg. 2. Grate firing furnace does not require preliminary treatment of solid waste except bulky waste like abandoned furniture. 3. Bearing excellent ability in solid waste decontamination, non-decayability, stabilization and volume reduction.	C	1. Suitable for solid waste with Hu of 2,000 kcal/kg or higher. 2. Preliminary treatment (pulverization) is required. 3. Excellent in decontamination, non-decayability, stabilization and volume reduction.	B	1. Suitable for solid waste with Hu of 2,000 kcal/kg and higher. 2. In general, preliminary treatment is not required except bulky waste. 3. The most excellent system in terms of decontamination, non-decayability, stabilization and volume reduction.	D	1. Not suitable for waste other than garbage. 2. Preliminary treatment (pulverization and classification) is required. 3. Volumes of unsuitable waste for composting and compost residue, which are still unstable, have to be separately treated. When landfilling them, they are not much volume-reducible, therefore inferior in space saving ability.
	Pollution prevention ability	B	1. Largest volume of air pollutant is generated (before treatment). 2. Treatment method (without discharge) of contaminated water is being developed. 3. Facilitates rank odour prevention.	B	1. Generation volume of air pollutant (before treatment) is less than (I) and (S.P). 2. Complicated process is required for treatment of the generated-gas cleaning. 3. No practical problems with rank odour prevention.	A	1. Generation volume of air pollutant (before treatment) is less than (I). 2. No technical difficulties with water pollution prevention. 3. No practical problems with rank odour prevention.	D	1. 100 - 300 ppm of NH_3 is generated in the process of fermentation. 2. In the case of open air secondary fermentation yard, treatment facilities of rainwater-mixed leachate is needed. 3. Rank odour prevention is difficult. 4. Consideration is required so as not to spoil the surrounding scenery.
		A	1. If large size of waste heat boiler-attached mechanical incinerator is adopted, the most effective energy recovery is realized by means of steam turbine power generation or heat (or could be cool water) supply. 2. When solid waste has Hu = 1,000 kcal/kg, sufficient electric power for the selfsupporting of the plant is generated. With higher Hu, power supply to outside consumers is possible. 3. The maximum resource recovery rate with the present solid waste composition is 40% (power generation + heat supply). 4. Stable land reclamation without fear of environmental contamination is possible with application of stabilized incineration residue.	C	1. Preliminary pulverization treatment is required so that power consumption of the plant increses 30–50% more than the case of grate firing furnace. 2. If solid waste Hu is less than 1,500 kcal/kg, power self-supporting system in the plant with solid waste energy alone is not realizable. With the higher Hu, surplus fuel or power is obtainable. 3. Land reclamation without fear of environmental contamination is possible with application of stabilized pyrolysis residue.	D	1. For slagging of incombustibles (ash), large volume of energy must be added. Normally, one of the following auxiliary fuels is supplied: heavy oil, LPG + Oxygen, or coke + oxygen + limestone. 2. When solid waste Hu is less than 2,000 kcal/kg power self-supporting system is not realizable even if auxiliary fuel is added. 3. Stable land reclamation without fear of environmental contamination is possible with the residue.	B	1. Energy recovery is impossible. 2. Approximately 15% on an average (wet basis) of urban waste is recovered as compost. 3. Able to recover ferrous metal. 4. Maximum resource revovery rate is approx. 20% (compost + recovered ferrous metal). 5. In case that unsuitable waste for composting is not incinerated but landfilled together with compost residue, stable land reclamation is not possible, and precautional measures against environmental pollution are necessitated.
Operational factor	Maintain-ability	B	1. Highly sophisticated knowledge and practical experience are required for the maintenance. 2. Since this technology has a long experience, standard for the maintenance are firmly established.	D	1. Highly sophisticated knowledge and practical experience are required for the maintenance. 2. Pulverizer requires careful operation and frequent maintenance. 3. Combustible gases are produced therefore, countermeasures against explosion are necessary.	C	1. Highly sophisticated knowledge and practical experience are required for the maintenance. 2. Combustible gases are produced, therefore, countermeasures against explosion are necessary.	A	1. Neither particular knowledge nor long experience is required.
	Practicality	A	1. This has a long experience, and is reliable and practical technology. 2. Presently, practical maximum capacity of a unit incinerator is said to be 500 t/d.	D	1. The technology is still under development. Cases of construction of the practical plant are very few. 2. Practical maximum capacity of the plant is 200 t/d.	C	1. The technology is presently under development. 2. Practical maximum capacity of the plant is 200 t/d.	A	1. Same as incineration, this method also has a long history and abundant results. 2. Technically, there are few constraints to limit practical maximum capacity.
Economic factor		B (A)	1. Construction cost index: 100 2. Operation and maintenance cost index: 100 3. Benefit by resource recovery: 30–40 kW·h/(solid waste) of electric power can be sold.	C	1. Construction cost index: approx. 150 2. Maintenance cost index: approx. 160 3. Benefit by resource recovery: 0	D	1. Construction cost index: approx. 180 2. Maintenance cost index: approx. 330 3. Benefit by resource recovery: 0	A (B)	1. Construction cost index: 70 (If incineration facility for treatment of the unsuitable waste are attached, the index will be higher than the case of incineration only. 2. Operation and maintenance cost index: approx. 60 (The same as the above comment in parentheses.) 3. Benefit by resource recovery: 100 - 150 kg/(solid waste) of compost is producible.
Institutional factor			1. Demonstrative effects are expectable. (The plant can be taken as a model of modern clear enterprice.)		1. Development of this method was initiated aiming at recovery of fuel gas or oil. Today, However, resource recoverability of this method is inferior to incineration. Even from a political viewpoint, this method is not attractive.		1. Recovery of fuel gas was a target of the method development. Today, as a matter of fact, the plant cannot be operated without large volumes of auxiliary fuel. This would rather be called resource consuming technology. Politically this method is not recommendable.		1. Continuation of this method is BMA's policy presently. 2. For improvement of compost quality, separate collection of garbage is desired. 3. Establishment of compost sale network is an indispensable condition for expansion of composting capacity.
Overall evaluation			A		C		D		B

Note 1. Importance of evaluation symbols A > B > C > D
2. Evaluation made in column of 'Economic factor' is based on the following conditions:
(1) Solid waste lower calorific value Hu = 1,200 kcal/kg.
(2) Steam boiler and steam turbine power generation equipment are attached to the facilities of (I), (P) and (S.P).
(3) The figures are derived from the cases in Japan.
(4) The evaluation results enclosed by parantheses in the columns (I) and (CP) correspond to the column 'Economic factor' and are applicable when incineration facilities for treatment of unsuitable waste for composting are attached to the compost plants.
3. Original evaluation from viewpoint of 'Institutional factor' was not attempted by the Study team as it was believed to be well done by BMA.

Fig. AP 4.10-(1) Process flow chart

Incineration (grate type)



Note: 1. Plant capacity; 150 t/24 h - grate firing furnace x 3 units = 450 t/24 h.
2. Steam volume to be constantly and stably supplied to steam turbine power generation facilities is set in 80% of the mean volume, considering fluctuation of steam volume and electric power consumption in the plant.
3. (W): means wet basis.

Fig. AP 4.10-(2) Process flow chart

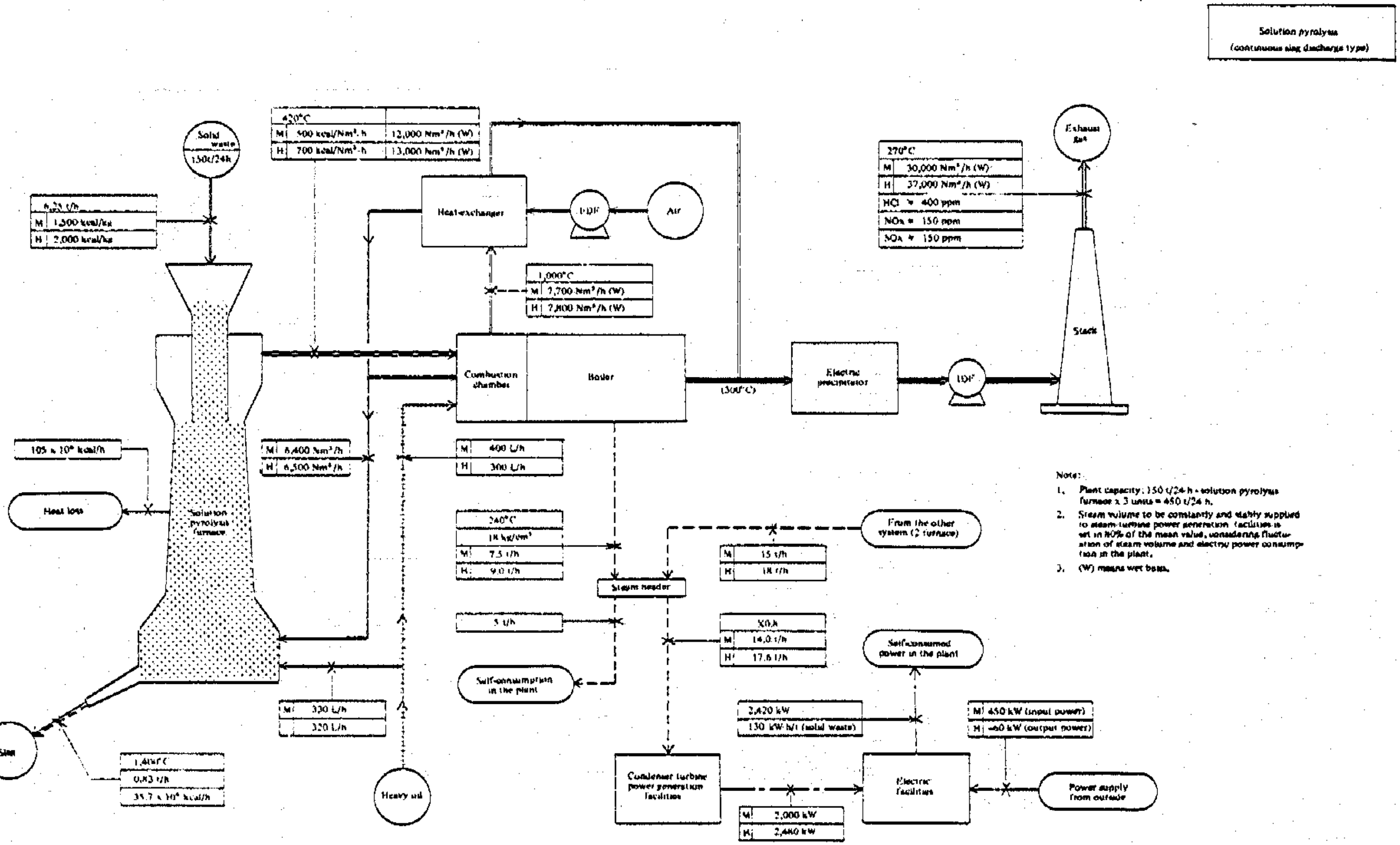
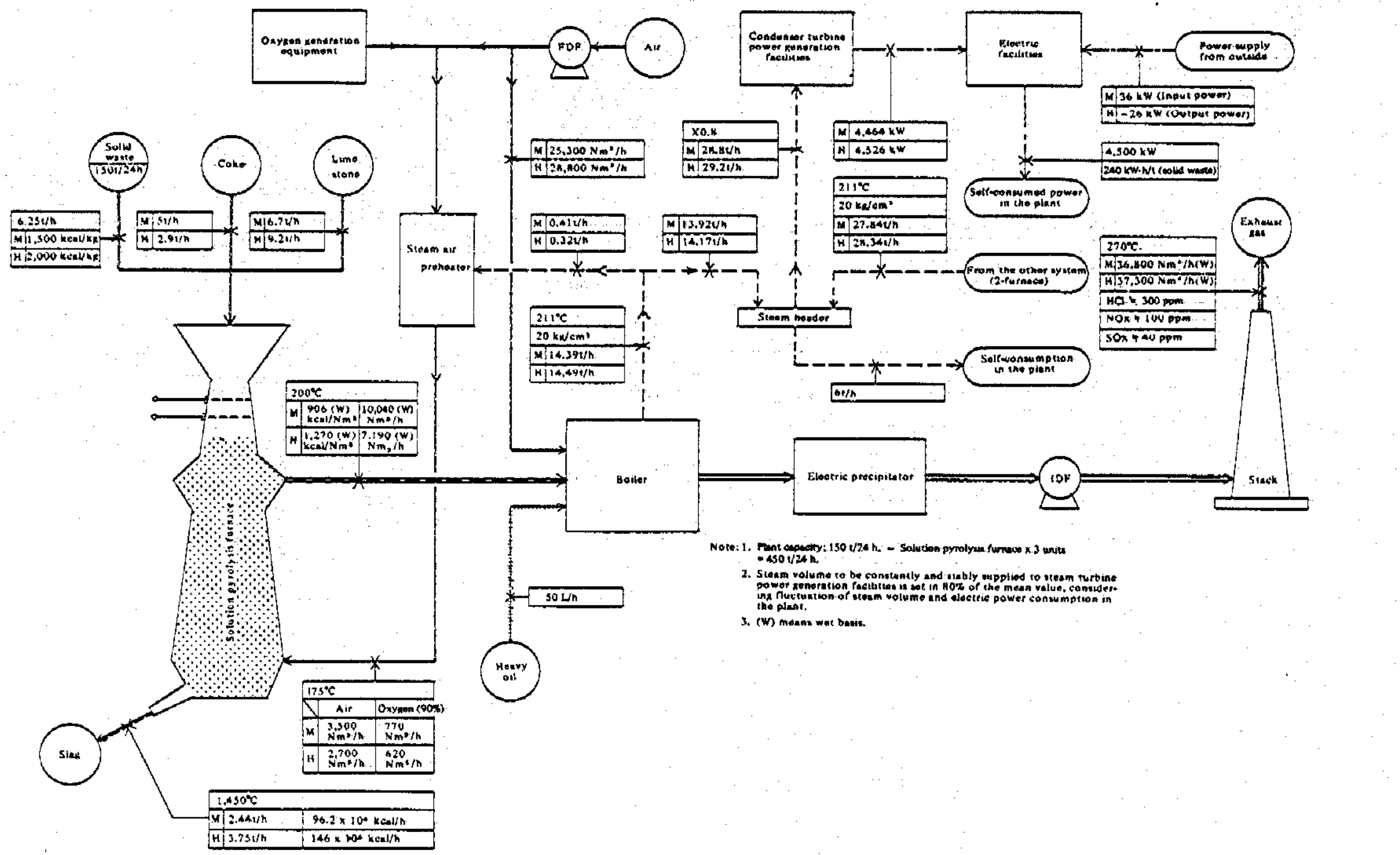


Fig. AP 4.10-(3) Process flow chart

Solution pyrolysis
(intermittent slag discharge type)



Note: 1. Plant capacity: 150 t/24 h. ~ Solution pyrolysis furnace x 3 units = 450 t/24 h.

2. Steam volume to be constantly and stably supplied to steam turbine power generation facilities is set in 80% of the mean value, considering fluctuation of steam volume and electric power consumption in the plant.

3. (W) means wet basis.

Fig. AP 4.10-(4) Process flow chart

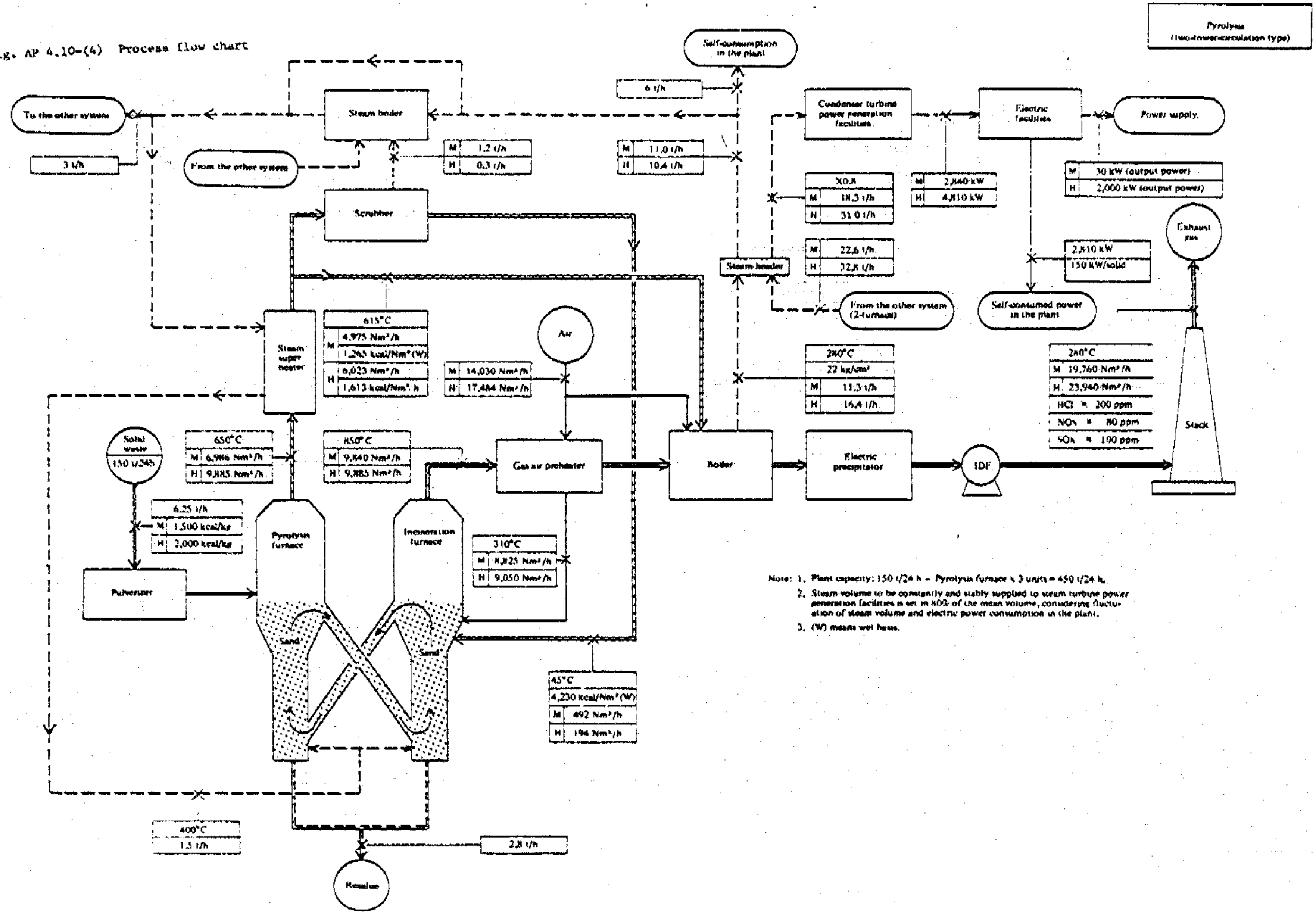


Fig. AP 4.10-(4) Process flow chart

Note: 1. Plant capacity: 150 t/24 h – Pyrolysis furnace × 3 units = 450 t/24 h.
2. Steam volume to be constantly and stably supplied to steam turbine power generation facilities is set in 80% of the mean volume, considering fluctuation of steam volume and electric power consumption in the plant.
3. (W) means wet basis.

Appendix 4.9 Technical study of final disposal

(1) General aspects of landfill disposal

i) Purposes of landfill disposal

Purposes of landfill disposal are, first of all, to store solid waste in a proper manner that should assure security of living environment and then, to stabilize the stored solid waste (converted to soil) and to decontaminate it (to be non-toxic and non-biodegradable) in a natural metabolic cycle.

ii) Character of landfill disposal

Landfill disposal is one of the final solid waste disposal subsystems. Dumping into the ocean is often referred to as another method of final disposal but, in the case of Bangkok city, it cannot be considered as a realistic or practical method. Therefore, when final disposal system is referred to in the Study, it automatically means landfill disposal.

Landfill disposal is, from viewpoint of a material recirculation cycle of the nature, a process to return the material wastes from human life activities to nature. From the technical point of view, it is a process to reclaim land utilizing solid waste as the reclamation material, requiring occupation of the land until completion of the reclamation.

On the other hand, from the viewpoint of neighbouring inhabitants' eyes, landfill disposal may be a nuisance which may cause deterioration of their living environment.

iii) Functions of landfill sites

Landfill sites should possess the following functions:

- economical and able to offer sufficient landfill capacity,
- easy for collection trucks to approach and permit disposal of incoming solid waste,
- able to make landfilled solid waste non-toxic, harmless and non-biodegradable in a relatively short period of time,
- prevent the occurrence of pollution from landfill site or the reclaimed land; inexpensive in pollution control cost and shorter in time for pollution control of completed landfill,
- safe from accident and ability to be coordinated with the surrounding environment,

iv) Considerations for landfill disposal

Landfill disposal has several merits and demerits.

Reclamation of unutilizable swamps is one of the merits.

The largest demerit is a fact that, whatever countermeasures are used, landfill disposal still remains as environmental deteriorating factor. Therefore, landfill disposal should not be quickly adopted simply because it is inexpensive, but should be deliberately examined in its negative influence to the future environment. As a rule, volume reduction and conversion to landfill material of solid waste should be intended as much as possible before initiating landfill disposal and, when landfill is inevitably adopted, all possible means to prevent environmental deterioration should be taken.

Environmental protection is realizable not only by spending a lot of money for the facilities, but also by improving the landfill method itself. For this purpose, correct information about local characteristics, composition of solid waste to be landfilled, and so forth should be obtained.

(2) Decomposition of solid waste at landfill site

i) Decomposition process of decomposable waste

a. Decomposition by microbes in soil

Readily decomposable substances like carbohydrate and protein are decomposed by microbes in the soil and converted to low molecular medium poroducts such as saccharides, organic acid and alcohol. Hence, they are transformed into the final form of water, gases, and inorganic salts. Decomposition of some decomposable substances is extremely slow, but after repetition of decomposition and polycondensation, they are transformed to relatively stabilized humus.

The sort of microbes influential in decomposition differs with the interval condition of landfill layer. When abundant air exists between solid waste layers in the initial stage of landfilling, aerobic decomposition progresses due to oxidation by aerobic bacteria. In general, however, anaerobic decomposition is dominant at landfill sites since air-permeability of landfill layers is usually low and most of the remaining oxygen in consumed by microbes.

Particularly in the case of landfilling into swampy sites where moisture content in solid waste is increased, an anaerobic atmosphere is rapidly created that causes generation of methane gas and other rank-odoriferous gases and corrosive solid waste leachate. As a result of solid waste decomposition, some spaces arise between landfill layers, but the spaces are crushed by weight of landfill layers themselves.

Thus, landfill layers are compressed and transformed into dense, tight and stable structures.

Rainwater penetrates through landfill layers. Soluble substances produced by microbic decomposition are dissolved into penetrated rainwater and form leachate.

b. Conditions to promote decomposition

Landfilled solid waste is decomposed by soil-microbes. To stabilize landfill layers in a shorter time, the atmosphere in landfill layers should be maintained for the alternative existence of aerobic and anaerobic microbes.

For this purpose:

- Proper water drainage should be arranged and sufficient air-permeability maintained.
- Solid waste should be pulverized in advance of the landfilling to increase microbic contact with the solid waste.
- Decomposition of cellulose and other substances readily decomposable in high temperature should be promoted by application of fermentation heat.

For effective achievement of the above measures, landfill covering soil and overlay method should be deliberately determined. Naturally, landfilling of substances obstructing the decomposition of soil-microbes is undesirable.

If such substances which may seriously affect moisture content or pH of landfill layers are to be landfilled, certain countermeasures are required such as mixing landfill with other materials.

ii) Disintegration of non-decomposable waste

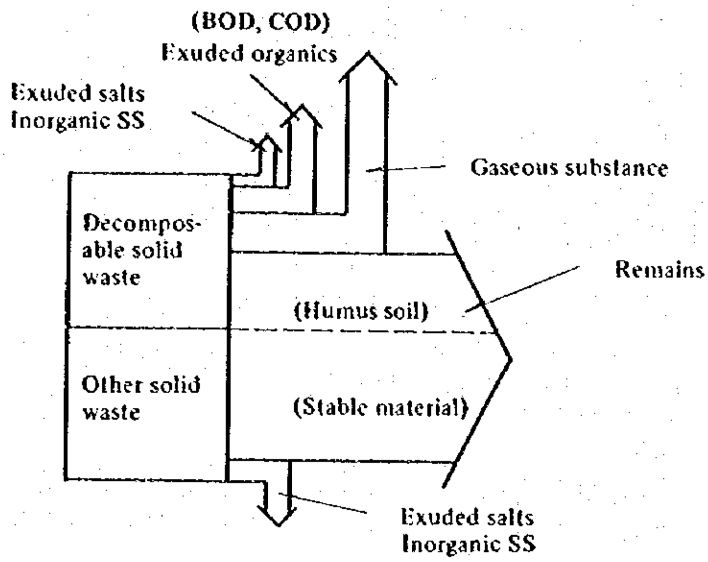
Sand, construction waste, plastics, metals, glass, incombustibles in incineration residue, slag, etc., are non-decomposable in soil. These sorts of solid waste undergo physical change such as compression under the weight of solid waste itself and movement of solid particles by water penetration. The physical change makes layer of non-decomposable waste more dense and stable. This change, however, is extremely slow in comparison with biochemical decomposition of decomposable waste.

Soluble salts in solid waste (sodium ions, calcium ions, chlorine ions, etc.) are dissolved in penetrated water which oozes out as leachate. After dissolution, some salts are absorbed into soil particles, humus soil, or other substances having high ion exchangeability. Sulfuric acid ions and nitric acid ions are normally reduced into hydrogen sulfide and nitrogen gas, respectively.

Metals and heavy metal ions contained in incineration residue are thought corroded, ionized, dissociated and dissolved into penetrated water in a chemical reaction through the media of moisture, oxygen, or organic acid and carbonic acid gas generated in the course of biochemical decomposition in landfill layers. Since the inside of landfill layers is usually anaerobic, dissociated heavy metal ions are either transformed into stable sulfide by the medium of hydrogen sulfide or absorbed into soil particles and humus soil. This functions to reduce the heavy metal content in leachate.

Fig. AP 4.11 below illustrate a model of material balance in decomposition mentioned above in paragraphs i) and ii).

Fig. AP 4.11 Decomposition of solid waste at landfill sites



Source : 1980-report by Japan Waste Management Association

(3) Landfill methods

i) Landfill structure

The structure of landfilled waste layers is classified into five types: anaerobic landfill, anaerobic sanitary landfill, improved anaerobic sanitary landfill, semi-aerobic sanitary landfill, and aerobic sanitary landfill. The evaluation of landfill structure follows this order. It is a proven fact that the more evolved the landfill structure is, the more it contributive to elimination of pollution factors.

Figure AP 4.12 shows types of landfill structures.

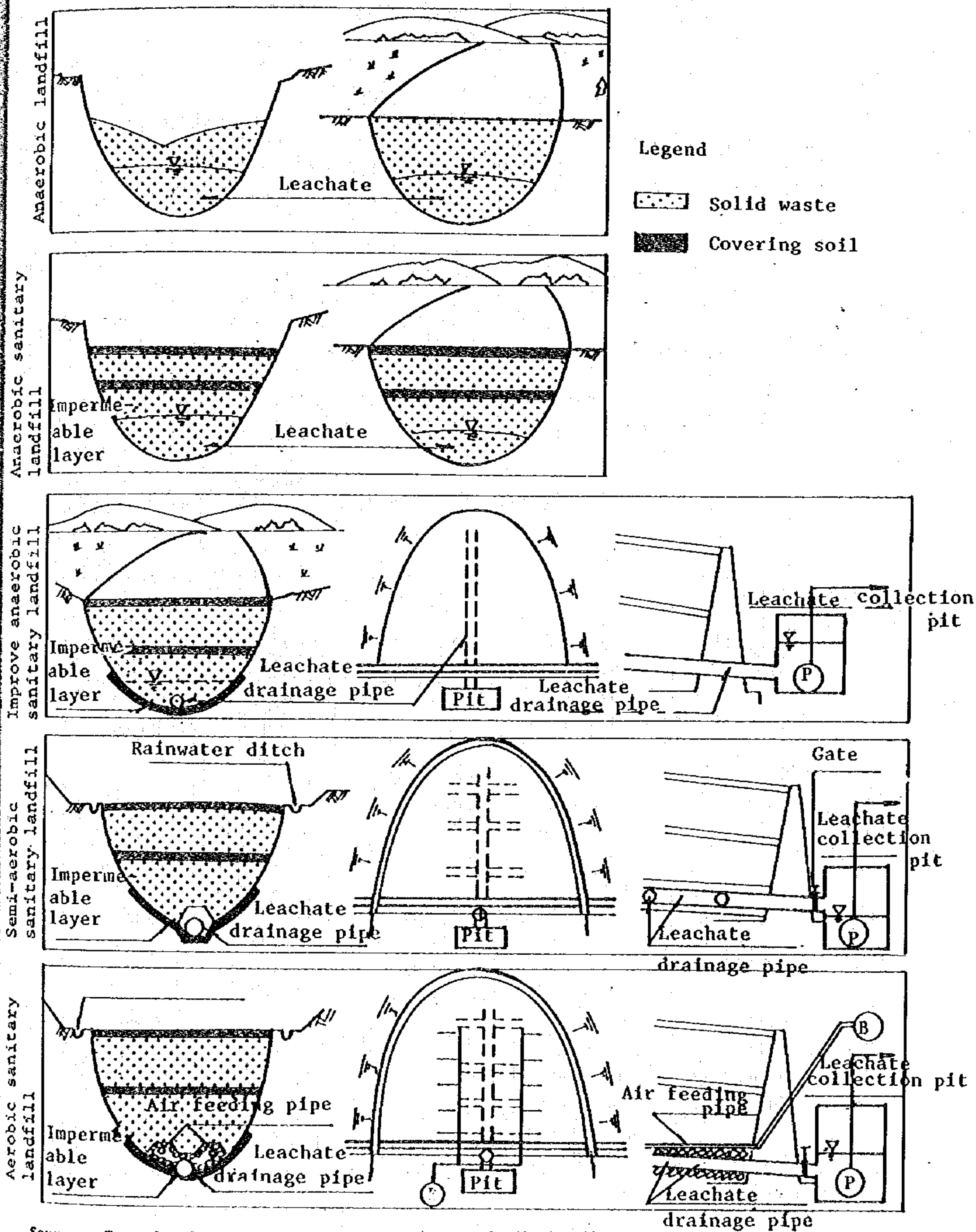
a. Anaerobic landfill

Leachate generated in landfill layers is scarcely drained but remains inside, that keeps landfill always in an anaerobic state. Quality of leachate is extremely deteriorated, which causes rank odour and breeding of vector and vermin (flies, rats, etc.). Anaerobic landfill can be said to be an uncontrolled landfill structure.

b. Anaerobic sanitary landfill

Overlay with covering soil is made each time when landfill layer reaches a certain thickness. Though this prevents generation of rank odour, fire, vector and vermin, the problems of leachate and gas generation remain.

Fig. AP 4.12 Types of landfill structures



Source: Text for Japan-USA Solid Waste Conference by M. Hanajima

iii) Improved anaerobic sanitary landfill

In addition to overlay with covering soil, drainage is provided to drain accumulated leachate at the landfill bottom. Owing to this arrangement, the quality of leachate is much improved as compared with the above two cases.

iv) Semi-aerobic sanitary landfill

Accumulated leachate at landfill bottom is promptly discharged through a drain pipe. The pipe also permits the natural inflow of air. This structure speeds up the decomposition of solid waste. The quality of leachate is also much improved.

v) Aerobic sanitary landfill

Air is forcibly fed into landfill layers in order to keep them in an aerobic atmosphere so that the solid waste is rapidly decomposed and stabilized. Leachate quality is highly improved with this method. A difficulty with this method is its high operating cost.

Change of leachate quality with the passage of time with each landfill structure is shown in table Table AP 4.17 and Fig. AP 4.13.

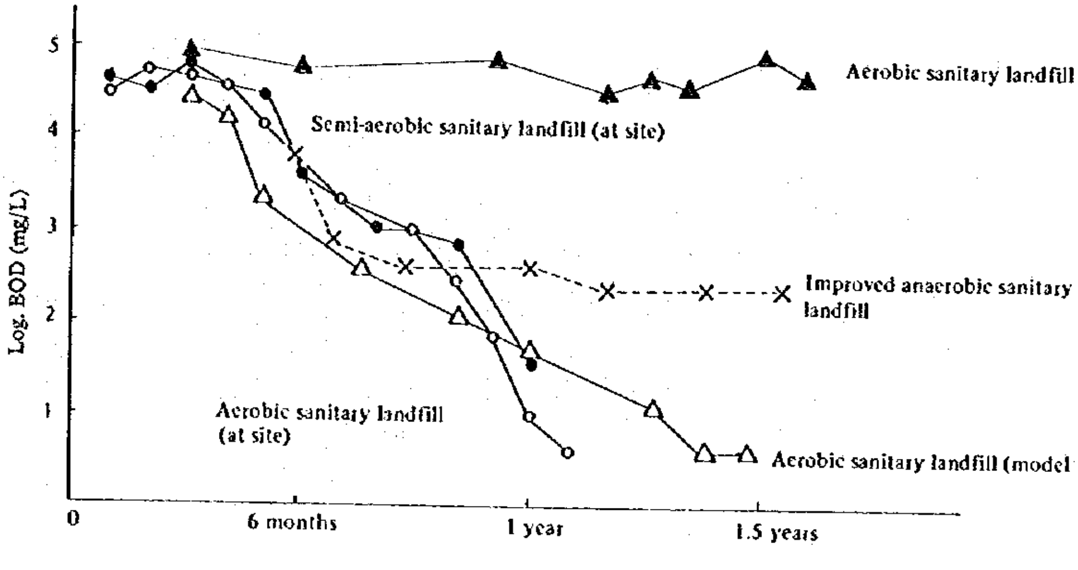
Table AP 4.17 Landfill structures and quality of landfill leachate

Structure	Item \ Time	Under landfill	6 Months after completion of landfill	1 Year after completion of landfill	2 Years after completion of landfill
Anaerobic landfill	BOD (mg/L)	40,000–50,000	40,000–50,000	30,000–40,000	10,000–20,000
	*COD (mg/L)	40,000–50,000	40,000–50,000	30,000–40,000	20,000–30,000
	NH_3–N(mg/L)	800– 1,000	1,000	800	600
	pH	Approx. 6.0	Approx. 6.0	Approx. 6.0	Approx. 6.0
	Transparency	0.9–1.0	1–2	2–3	2–3
Improved Anaerobic sanitary landfill	BOD (mg/L)	40,000–50,000	7,000– 8,000	300	200–300
	*COD (mg/L)	40,000–50,000	10,000–20,000	1,000– 2,000	1,000– 2,000
	NH_3–N (mg/L)	800– 1,000	800	500–600	500–600
	pH	Approx. 6.0	Approx. 7.0	7.0–7.5	7.0–7.5
	Transparency	0.9–1.0	1–2	1.5–2	1–2
Semi-aerobic sanitary landfill	BOD (mg/L)	40,000–50,000	5,000– 6,000	100–200	50
	*COD (mg/L)	40,000–50,000	10,000	1,000– 2,000	1,000
	NH_3–N (mg/L)	800– 1,000	500	100–200	100
	pH	Approx. 6.0	Approx. 8.0	Approx. 7.5	7.0–8.0
	Transparency	0.9–1.0	1–2	3–4	5–6
Aerobic sanitary landfill	BOD (mg/L)	40,000–50,000	200–300	50	10
	*COD (mg/L)	40,000–50,000	2,000	1,000	500
	NH_3–N (mg/L)	800– 1,000	50	10	1–2
	pH	Approx. 6.0	Approx. 8.5	7–8	Approx. 8.5
	Transparency	0.9–1.0	6–7	2–3	2–5

* Analysed by $K_2Cr_2O_7$ method

Source: Urban solid waste disposal guide book.

Fig. AP 4.13 Change of BOD of leachate with passage of time with each landfill structure



Source: 1979-report by Japan Waste Management Association

ii) Overlay

Sanitary and well-planned landfill of solid waste will bring forth stable reclaimed land in shorter periods of time. Fundamental actions to this end are to lay solid waste evenly on the site, to pressurize the surface with roller and then, to overlay the surface with covering soil.

a. Thickness of solid waste layer

Thickness of the layer of solid waste is generally standardized as 3 meters; this is certainly not a fixed figure, but variable according to nature of solid waste, applicability of landfill method, topography of landfill site, expected utility of the completed landfill site, environmental conditions of the surroundings, and so forth.

b. Function of overlay

- To prevent breeding of vector and vermin such as mosquitoes, flies and rats
- To prevent diffusion of dust and solid waste
- To prevent diffusion of rank odour
- To prevent outbreak of fire
- To maintain scenic adequacy
- To promote stabilization of the site ground
- To reduce leachate volume (Drainage of rainwater should be separately arranged.)

c. Timing of overlay

Overlay should be made on the basis of the following timing:

a. 'On-the-day overlay' is made in either case when landfill work of the day is completed or when certain area is landfilled with the specified thickness of solid waste.

b. 'Intermediate overlay' is made before temporary ceasing of landfilling.

c. 'Final overlay' is made when landfilling is completed.

d. Thickness of covering soil layer

Thickness of the layer of covering soil is determined based on the nature of solid waste, applicability of landfill method, effect on pollution prevention, nature of covering soil, etc. Generally, a thickness between 15 and 50 cm for on-the-day overlay and between 50 and 100 cm for final overlay are adopted.

Relation between thickness of covering soil layer and its effect is shown in Table AP 4.18.

iii) Landfill methods (Filling techniques)

Whichever landfill method is adopted the principle of landfilling is common to the other methods; namely, laying solid waste evenly, pressurizing and tightening it and overlaying it with covering soil to produce a landfill cell. On account of differences in solid waste replacement, there are three filling techniques.

a. Trench method (ref. Fig. AP 4.14)

The site is trenched and solid waste is thrown into the trench. After filling up the trench with solid waste, the surface is backfilled. On completion of trench landfill, another trench is made and backfilled in the same manner as above. Trenches are dug one after another in sequence.

The surplus soil which is dug up is saved for final overlay or for additional landfill on the completed trench. Generally, this method suits sites where groundwater level is low and ground surface is flat.

d. Area method (ref. Fig. AP 4.15)

Solid waste is piled up on the ground surface. Covering soil is usually conveyed from another location. This method is applicable to not only flat land but also sloping places, bottoms of valleys or any other uneven land.

Table AP 4.18 Thickness of covering soil layer and its effect

Kind of effect	Effect	Thickness of covering soil			
		Thick		Thin	
		Sandy soil	Clayey soil	Sandy soil	Clayey soil
Decomposition	Increase in air inflow	Δ	X	O	Δ
Pollution	Promotion of gas diffusion	O	X	O	X
	Prevention of vermin & vector breeding	O	O	X	X
	Prevention of solid waste diffusion	O	O	O	O
	Improvement of scenic condition	O	O	O	O
	Prevention of rank odour diffusion	X	O	X	Δ
	Prevention of fire outbreak	O	O	O	O
	Prevention of rainwater penetration	X	O	X	Δ
Labour	Ease of landfill work	O	X	Δ	X
	Landfill work volume	X	X	O	Δ
	Increase of landfill capacity	X	X	O	O
Landfilling	Saving of covering soil volume	X	X	O	O
	Acquisition of covering soil	X	Δ	X	O
	Promotion of ground stabilization	O	Δ	Δ	X

Source: Tokyo Metropolitan Government

Note: O mark means 'superior' or 'good',
Δ mark means 'moderate' or 'fair',
X mark means 'inferior' or 'poor'.

Fig. AP 4.14 The trench method

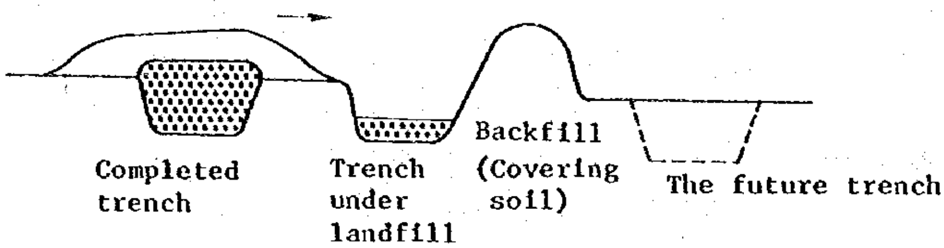
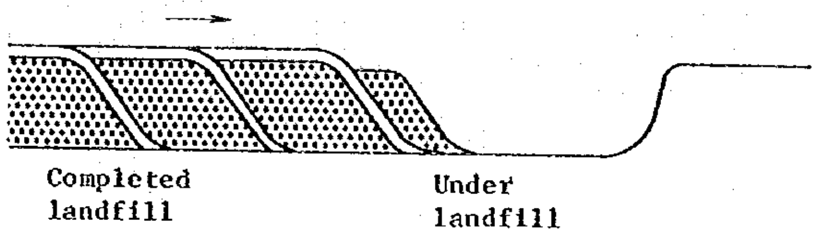


Fig. AP 4.15 The area method



c. Combination method

This method is a combination of the trench method and the area method. As the case maybe, a hillside in landfill site is cut away to obtain covering soil.

d. Classified landfill method

Other than the above landfill techniques, there is the classification landfill. It is not specifiable as a technique but can be categorized as an independent landfill method.

The specific character of this method is to segregate landfill solid waste into sectioned sites according to the nature of the solid waste. From the condition of the reclaimed land-use plan or site ground condition, the classified landfill method is often adopted as preferable.

Decomposable solid waste, with its remarkable volume-reducibility even after completion of landfill, is not landfilled in a site where ground subsidence should be avoided, but is applied to land reclamation for parks, meadows or any other purposes on which ground subsidence has no seriously effect. On the other hand, incineration residue and other inorganic waste are exclusively landfilled into a site where the ground must not subside. If uneven subsidence should be avoided, pulverization of solid waste before landfilling is an effective countermeasures.

For implementation of the classiffied landfill, some increased field supervision is unavoidable, such as directing each collection truck to the proper landfill site according to nature of its solid waste.

e. Landfill work

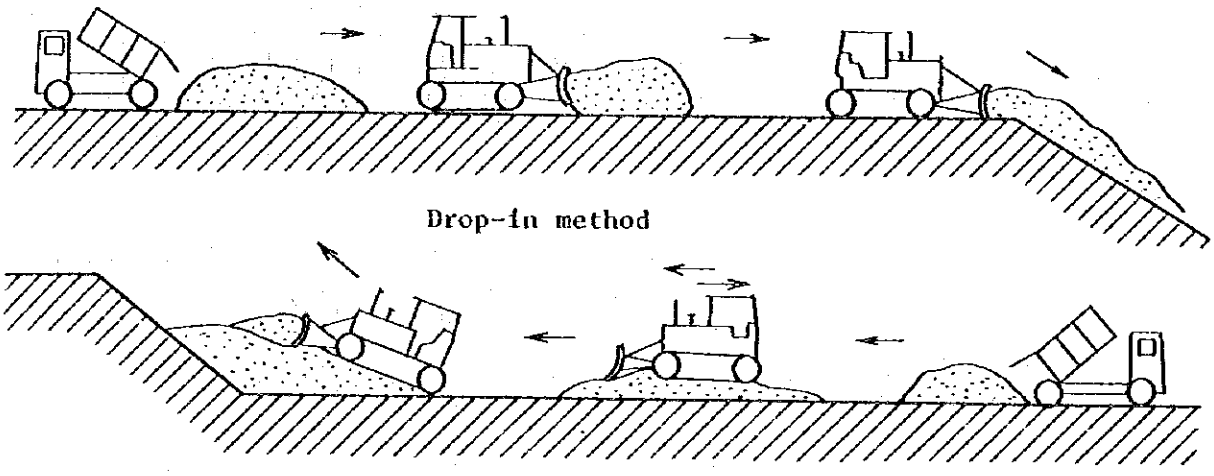
Even-placement and roller-tightening of solid waste are basic technique, of landfill work with which uneven subsidence can be avoided and landfill efficiency raised.

For the even-placement, the following the methods are commonly adopted. (ref. Fig. AP 4.16)

a. Drop-in method. Work efficiency is higher but evenness of solid waste layer is not well controlled. Inconvenient for sufficient roller-tightening.

b. Push-up method. Able to make up for defficiency of drop-in method, but work efficiency is inferior.

Fig. AP 4.16 Solid waste replacement method



Push-up method

iv) Pre-treatment

Pre-treatment (Auxiliary operation) is a preparatory solid waste treatment process prior to landfilling, aiming at volume reduction, non-biodegradation and conversion of solid waste to landfill material. As typical methods of pre-treatment, pulverization and baling are commonly adopted.

a. Pulverization pre-treatment

There are three methods of pulverization: rotary method (shearing type or impact type), reciprocation method (shearing type or compression-shearing type) and compression method.

Among them, rotary method impact type pulverizer is the most popular.

Merits and demerits of pulverization are as follows:

Merits:

- Solid waste is evenly pulverized which highly contributes to volume reducibility.
- Pulverized solid waste increases its surface area, that promotes its decomposition and results in quick stabilization.
- Pulverization makes landfill work easier.
- Breeding of vector and vermin is suppressed.
- Pulverization facilitates resource recovery (material retrieval).

Demerits:

- Causes vibration and noise pollution.
- Explosive materials are often mixed in solid waste. Pulverization of explosive materials could cause a serious explosion.
- The treatment cost is relatively high.

b. Baling pre-treatment

This treatment aims at volume reduction and non-biodegradation of solid waste.

Solid waste is compressed and solidified into a certain size of blocks. The blocks are wrapped up with metal net or coated with asphalt according to the purpose of solidification.

Compression-solidification was once applied to solid waste treatment in Japan but has ceased being used except for treatment of incombustible bulky waste because it was not so effective in volume reduction and, what was worse, it prolonged generation of leachate.

(4) Generation of pollution at landfill site, and its prevention

Solid waste landfill could be accompanied with miscellaneous kind of problems, such as water pollution by leachate, rank odour from generated gas, fire negative influence on plants, subsidence of ground, dust and waste diffusion, breeding of vector and vermin, traffic congestion, etc. The word pollution covers all these problems.

i) Solid waste leachate

The following figure (Fig. AP 4.17) shows a concept of leachate generation process caused by decomposition of solid waste in landfill layer.

Among miscellaneous components of landfilled solid waste, garbage is first converted to solubles, then semi-dissoluble material is gradulally decomposed. Up to this point, the relation BOD'=. COD is thought to be maintained.

When decomposition progresses further, dissoluble material volume is reduced so that semi-dissoluble material volume is relatively increased and composition of leachate is made more complicated. Quality of leachate is much influenced by both solid waste decomposition process and thinning or wash-out effect resulting from penetration of water into landfill (rainwater, ground water, underflow, etc.)

ii) Generation of gases

Under aerobic conditions, landfill layers produces carbonic acid gas and, under anaerobic conditions, they produce carbonic acid gas, methane gas and infinitesimal amounts of gases such as hydrogen sulfide and ammonia.

Methane gas is combustible, which introduces the risk of explosion for the mixed gases. Therefore, if an ignition source exists among the landfilled waste, methane gas could cause a fire. Methane gas is apt to remain in closed area like backyards of buildings and can an explosion.

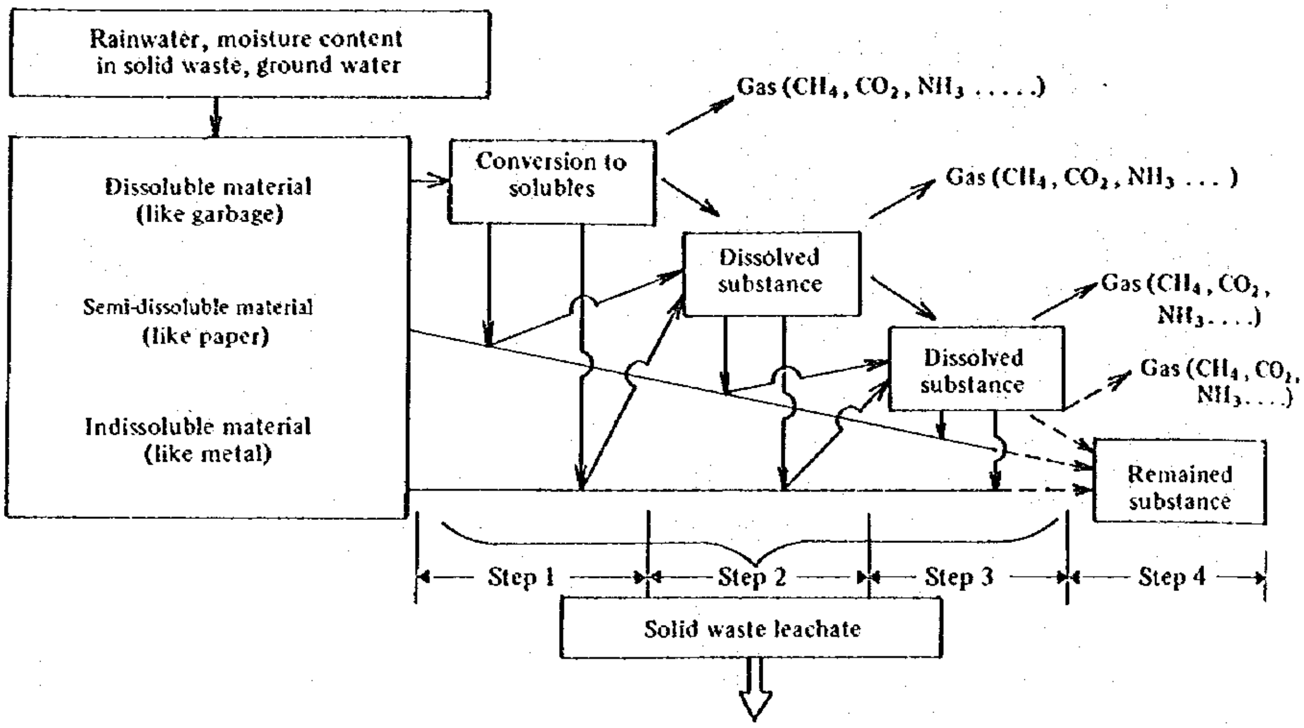
Hydrogen sulfide and ammonia, though their quantities are very small, cause rank odour. These gases sometimes obstruct respiration of plants and make them wither from lack of oxygen.

iii) Subsidence of solid waste layer

A common cause of subsidence of solid waste layers is the fall of a roof of hollow space in solid waste layer which is formed as the results of decomposition of landfilled waste. Subsidence of solid waste layers at under-landfill sites may cause few practical problems; however, proper measures for the quick stabilization of landfill site should be taken as frequent and long-lasting subsidence affects on the future land-use plan.

The relation between type of solid waste and pollution and between pollution and the preventive measures are displayed in Table AP 4.19 and 4.20 respectively.

Fig. AP 4.17 Concept of leachate generation process



Landfill Step	Step 1 Conversion Stage to Solubles	Step 2 First Conversion Stage to Inorganics	Step 3 Second Conversion Stage to Inorganics	Step 4 Stablization Stage
Gas	Start of gas generation. Dissolution of dissoluble substances	Gas generation activated. Dissolution of semi-dissoluble substances	Gas generation reduced. Accumulation of semi-dissoluble substances	Ceasing of gas generation. Disappearance of dissolved substances
Leachate	Incerase of dissolved substances.	Decrease of dissolved substances.	Decrease of dissolved substances.	Accumulation of remaining substances.
Leachate contents: Low molecular weight substances per high molecular weight substances	Low > High	Low ≒ High	Low < High	Low << High

Source : Tokyo Metropolitan Government.

Table AP 4.19 Solid waste and pollution

Disposed-of material	Pollution								
	Appearance	Diffusion or out flow of solid waste	Rank odour	Breeding of vector and vermin	Fire (burning of solid waste)	Oozing out of leachate	Generation of methane gas	Penetration of toxic substance into ground	Ground subsidence
Municipal solid waste	◎	◎	◎	◎	◎	◎	◎	◎	◎
Incombustibles	○	◎	○	△	△	△	△	○	△
Combustibles	◎	◎	◎	◎	◎	◎	◎	◎	◎
Incineration residue	△	△	○	△	△	○	○	◎	△
Sludge	◎	○	◎	△	△	◎	○	◎	◎
Sands, soil, pebbles	△	△	△	△	△	△	△	△	△

Source: Tokyo Metropolitan Government

Remark: ◎ Most causative
○ Causative
△ Less causative

Table AP 4.20 Pollution and preventive measures

Preventive measures	Type of pollution: Appearance	Diffusion or flow out of solid waste	Rank odour	Breeding of vector and vermin	Fire (burning of solid waste)	Oozing out of leachate	Generation of methane gas	Penetration of toxic substance into ground	Ground sub-sidence
Overlay	**O**	**O**	O	**O**	**O**	O	O		
Thickness of solid waste layer			O			O	O		O
Embankment	O	Δ				O			
Aeration			O	O		O	O		
Antidiffusion fence	Δ	**O**							
To make bottom impermeable						O		**O**	
Leachate collec-tion facilities						**O**		O	O
Gas collection facilities			Δ				**O**		
Deodorant			O						
Fire extinguish-ing facilities					O				
Insecticide				O					
Pulverization	O		O	Δ	Δ				
Compression	O	O	O	Δ	O	Δ			**O**

Source: Tokyo Metropolitan Government

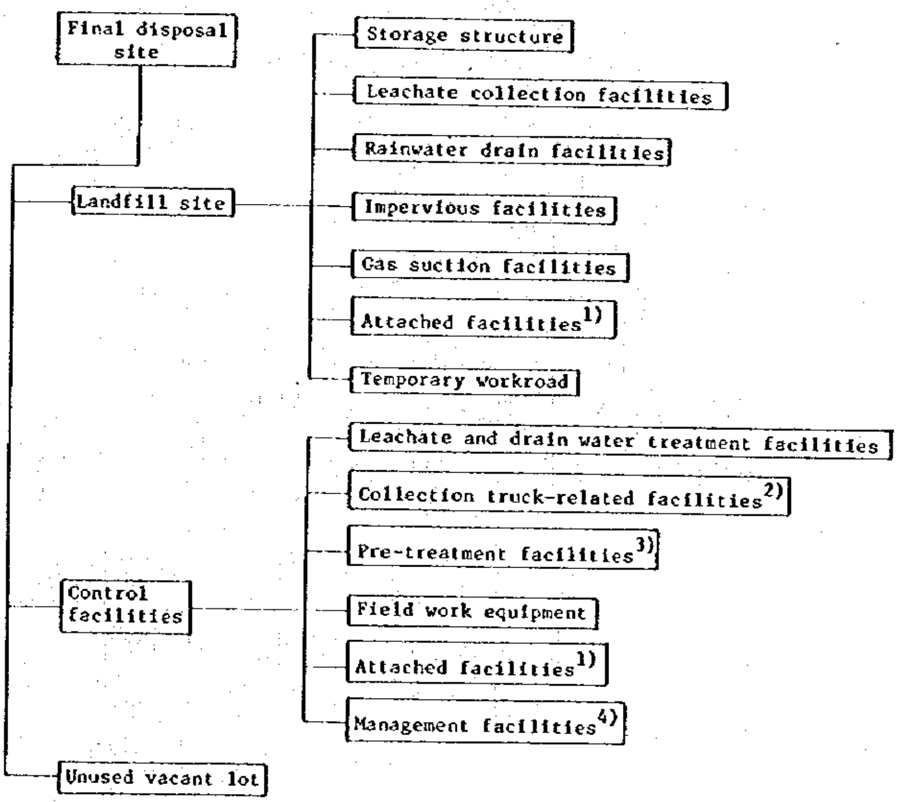
Remark: Δ Auxiliary counter measures
O Effective counter measures
O Principal counter measures

(5) Final disposal site facilities and equipment

i) Composition of the facilities

The following figure (Fig. AP 4.18) shows components of final disposal site facilities which are required for performance of final disposal functions mentioned in Section (1).

Fig. AP 4.18 Composition of final disposal site facilities



1) Attached facilities
- Diffusion prevention equipment
- Gas control equipment
- Fire and disasters prevention equipment
- Preventive facilities against vector and vermin

2) Collection truck-related facilities
- Access road (in-site roads, truck guide equipment)
- Reception facilities (inspection, weighing, recording facilities) Truck washing equipment

3) Pre-treatment facilities
- Volume reduction facilities
- Non-biodegradation (non-toxic, harmless) facilities

4) Management facilities
- Management office
- Garage, warehouse
- Sanitation facilities
- Communication facilities
- Utilities

Source : Urban solid waste disposal guidebook.

ii) Landfill work equipment is classified into two groups:

. Machines for solid waste placement and pressurizing

. Machines for trenching, covering soil cutting and overlaying.

Suitability of these machines are described in Table AP 4.21, and illustrations of the main types of machines are displayed in Fig. AP 4.19.

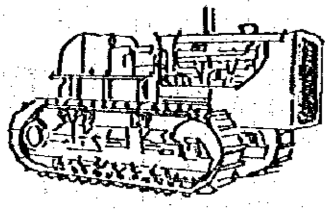
Landfill compactor is particularly excellent for pulverization and compression ability.

Table AP 4.21 Comparison of performance of landfill work machines

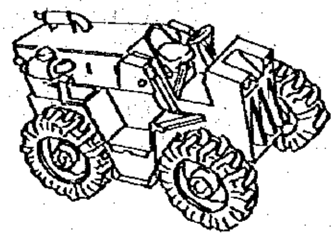
Machine Type	Solid Waste		Overlay			
	Level-ling	Pressur-izing	Trench-ing	Level-ling	Pressur-izing	Drag-ging
Crawler-dozer (Bulldozer)	Excell-ent	Good	Fair	Excell-ent	Good	Poor
Crawler-loader (Tractor shovel)	Good	Good	Excell-ent	Good	Good	Poor
Wheel-dozer	Excell-ent	Good	Fair	Good	Good	Poor
Wheel-loader	Good	Good	Fair	Good	Good	Poor
Scrape-dozer (Scraper)	Poor	Poor	Good	Excell-ent	Poor	Poor
Power shovel (Drag line)	Poor	Poor	Excell-ent	Fair	Poor	Poor
Compactor	Excell-ent	Excell-ent	Poor	Good	Excell-ent	Poor

Source: The text by Japan Environmental Sanitation Center

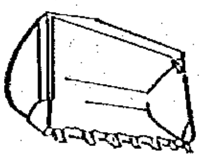
Fig. AP 4.19 Main machinery for landfill work



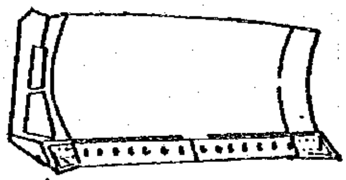
Crawler tractor



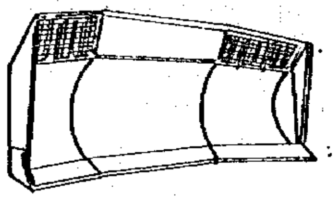
Wheel tractor



Common bucket

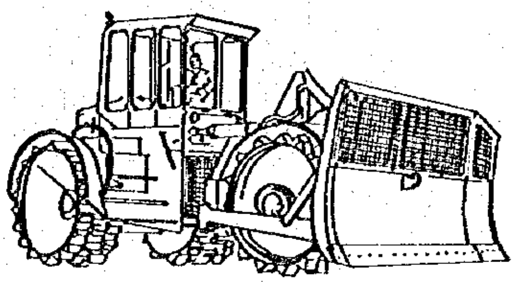


Dozer blade

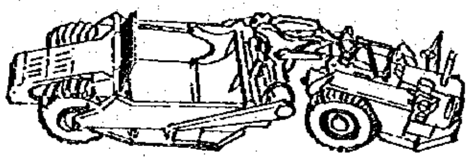


Landfill blade

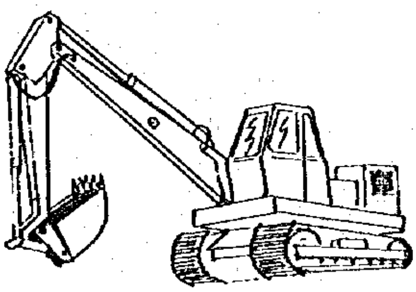
Attachment



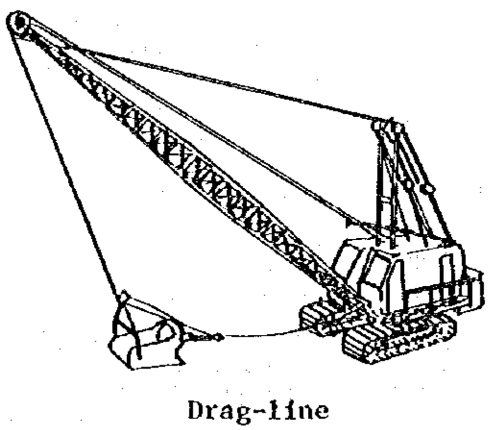
Landfill compactor



Scraper



Back-hoe



Drag-line

(6) <u>Use of the reclaimed land</u>

Decomposition of organic materials in landfilled solid waste takes a long time; it continues even after final completion of landfilling. As long as decomposition continues, operation of treatment facilities for landfill leachate, rank odour and generated gas should also be continued. This constrains early utilization of completed landfill sites.

Landfill reclaimed land is suitable for use as a park, athletic field, golf course, motorpool, open storage yard, farmland, orchard, and public facilities site; however, a clear picture of the future land-use plan should be set up and proper landfill method (ref. (3) iii) d) matching to the expected land use should be selected in advance of start-up of landfilling.

The land use plan should be of beneficial to the neighbouring inhabitants whose cooperation in establishment and operation of the landfill facilities is required.

(7) <u>Utilization of landfill sites for a long period of time</u>

The solid waste which is disposed of by landfill and left for some period, contains a small volume of moisture and is easy to burn during the dry season in Bangkok. After digging-out and simple sieving of such landfilled solid waste, the residue other than soil and sand can be incinerated easily.

With adoption of this method, it becomes possible to stabilize a landfill site, decrease various kinds of environmental polution and utilize the landfill site efficiently for a long period of time, As this method is considered to be an effective means from both view points of climatic condition in Bangkok and characteristics of final disposal site, it is recommended to carry out the technical and economic study of the feasibility of this method.

If the result of study is satisfactory, it will become possible to establish a system where a part of landfill site is regarded as pretreatment area of incineration facilities.

Appendix 4.10 Basic conditions for formulation of final disposal system

(1) State of the existing landfill

Landfill sites presently in operation in Bangkok city are located in swamps which are common topographic features of the city. The location makes rainwater drainage difficult, so that, once it rains, the surroundings of landfill sites look as if natural ponds were located there.

Although each landfill site is separated by a simple embankment and land filling is made inside the embankment, dense leachate oozes out and remains on the outskirts of the embankment. This is due to insuffcient leachate collection and drain facilities. Incoming waste is dumped on landfill using the open dump method and then levelled by bulldozer and wheel tractor.

Owing to unsanitary open dumping, various problems have arisen such as generation of rank odour, breeding of flies, diffusion of waste, etc., from which the neighbouring inhabitants suffer. To improve these circumstances, adoption of appropriate landfill methods for environmental protection are most urgent matter to be discussed.

(2) Basic conditions

In planning and designing the final disposal system, the following conditions and their mutual relations should be taken into deliberate considerations:

- Conditions relating to the solid waste to be landfilled
- Natural conditions concerning climatology, hydrology and geology
- Conditions relating to environmental protection
- Conditions relating to control and maintenance of landfill work
- Scale of landfill site, period of landfilling
- Reclaimed land use

i) Conditions relating to the solid waste to be landfilled

The sort of solid waste to be landfilled mostly depends what kind of intermediate treatment technology is adopted. It could be raw waste, incineration residue, or compost residue. Quality of leachate and volume of landfilled waste also vary according to the sort of solid waste.

An index to show final volume (m^3) of one ton of landfilled solid waste after being decomposed in landfill layer is called as a volume conversion coefficient.

The value of the volume conversion coefficient is influenced by the type and composition of solid waste, landfill method, shape of landfill, local characteristics, etc.; therefore, it is desirable to select the most proper figure of the coefficient from among the actually measured values from sites with similar conditions. In the case of Bangkok, however, applicable data showing the relation between solid waste volume and final volume after landfill were not available, so the coefficient was determined as follows based on the data obtained in Japan.

. Household waste composed mainly of combustibles;

in the case of open dump: 0.80 m^3/t

in the case of sanitary landfill: 0.88 m^3/t

. Compost residue: 1.00 m^3/t

. Incineration residue (ash): 1.00 m^3/t

ii) Climatology, hydrology and soils

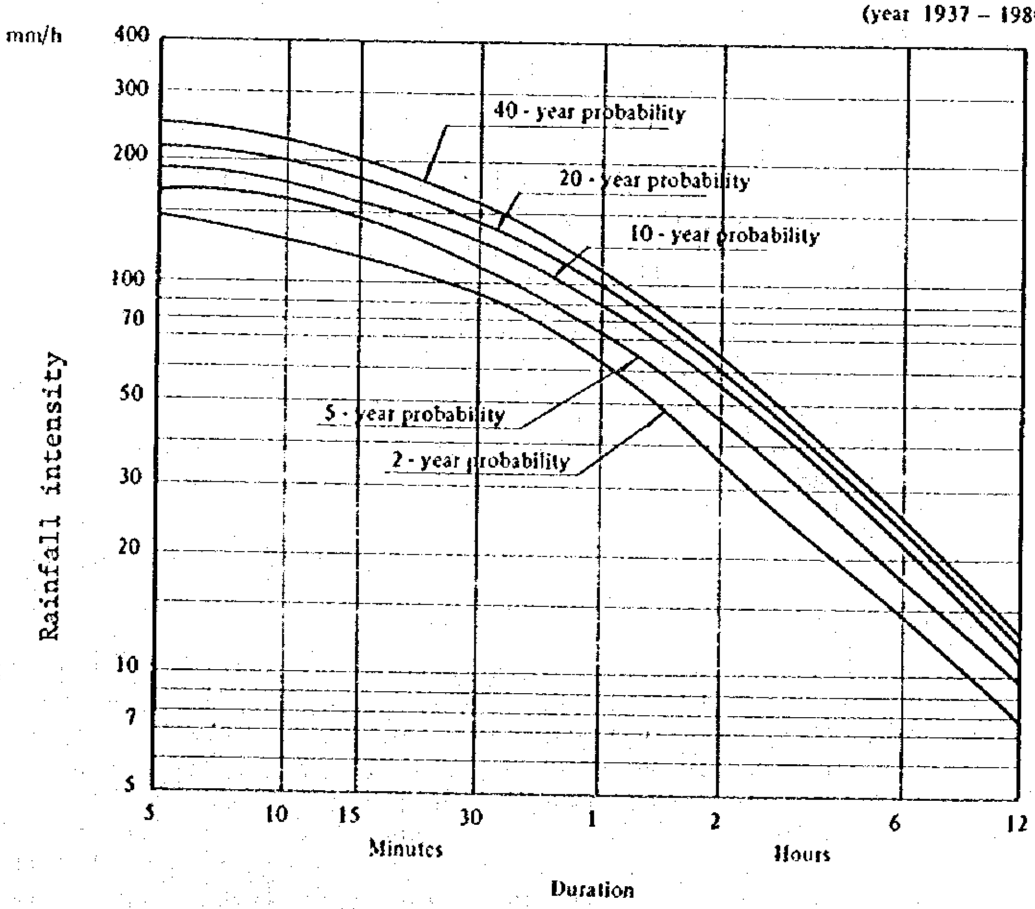
a. Climatology

Climate of the central Thailand (Bangkok metropolis) is clearly differentiated to rainy and dry seasons. Approximately 90% of annual rainfall 1,500 mm concentrates in the rainy season, and little rainfall is seen during the long dry season.

This makes selection of leachate treatment method difficult and operation of the treatment facilities delicate since quality and quantity of leachate changes from season to season. Average annual rainfall by months in Bangkok city is shown in Table AP 4.22. Figure AP 4.20 is to show rainfall intensity-duration curve in Bangkok.

Fig. AP 4.20 Rainfall intensity-duration curve in Bangkok

(year 1937 - 1980)



Source: Meteorological Department Ministry of Communications.

Table AP 4.22 Climatological data (1951 to 1975)

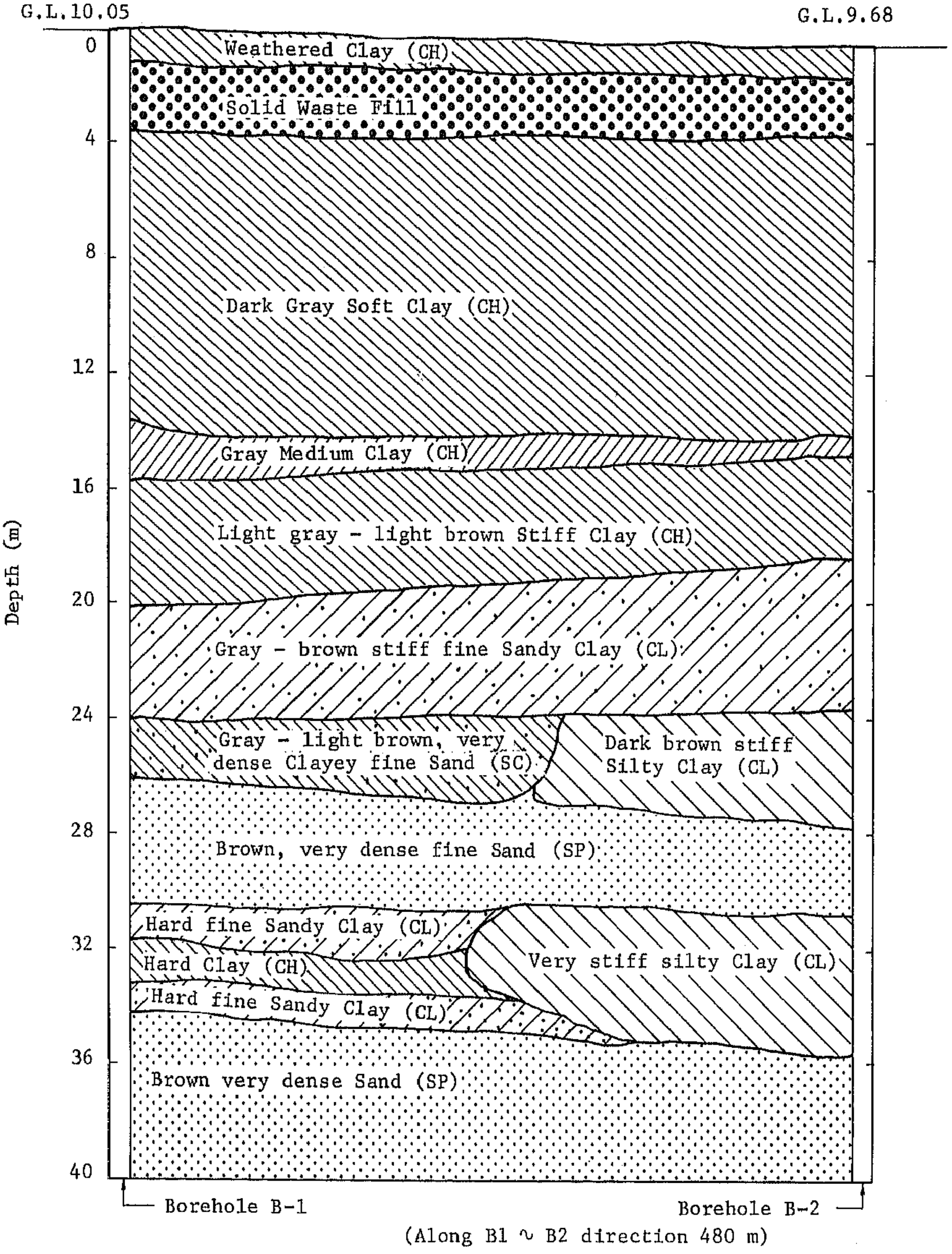
Station	Data type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Bangkok	Rainfall													
	Mean	8.9	29.1	28.0	70.0	185.1	150.4	171.3	206.8	402.1	234.2	47.6	10.4	1543.9
	Mean rainy days (mm)	1.8	2.8	3.6	6.4	15.8	16.5	18.4	20.8	21.6	17.4	6.0	1.6	132.7
	Greatest in 24 h (mm)	39.3	73.0	52.8	133.5	124.2	82.9	108.8	97.8	153.7	123.2	81.2	32.0	153.7
	d/Year	31/61	11/64	24/73	23/51	15/66	6/59	30/55	26/71	23/68	5/60	2/69	8/72	23/68
	Evaporation													
	Mean - Piche (mm)	98.0	88.8	108.8	105.7	90.2	81.8	78.3	71.2	58.1	58.7	69.3	87.0	995.9
	- Pan (mm)	132.8	139.2	179.8	182.6	162.6	145.8	141.6	140.3	126.2	120.7	118.8	123.9	1714.3
	Wind													
	Prevailing Wind	NE	S	S	S	S	S	SW	S	SW	NE	N	NE	-
	Mean Wind Speed (knots)	3.8	5.2	5.8	5.7	4.6	4.9	4.6	4.6	3.9	3.5	3.7	3.5	-
	Max. Wind Speed (knots)	31 NNE	37 N	48 ENE	56 E	42 W	43,SSW	43 SWW	45 WNW	44 SSW	40 NE	45 ENE	31 SE,NNE	-
Don Muang	Rainfall													
	Mean (mm)	7.4	18.0	39.9	63.4	165.7	163.6	164.5	223.3	302.6	238.8	36.8	17.1	1439.1
	Mean rainy days	1.4	2.3	3.5	6.3	14.2	15.5	18.0	20.3	21.4	16.2	6.0	1.8	126.9
	Greatest 24 h (mm)	31.5	48.4	50.4	106.2	78.6	116.5	81.8	117.5	148.4	132.9	34.3	48.8	148.4
	d/Year	19/75	18/61	27/74	26/61	4/61	20/53	3/60	23/62	6/72	1/57	30/70	13/70	6/72
	Evaporation													
	Mean - Pich (mm)	No Observation												
	- Pan (mm)	No Observation												
	Wind													
	Prevailing Wind	E	S	S	S	S	S	S	SW	S	N	N	N	-
	Mean Wind Speed (knots)	5.9	7.3	8.0	7.8	7.3	7.2	6.8	7.1	6.6	6.0	6.1	3.9	-
	Max. Wind Speed (knots)	35 E, ESE	33 E	85 NE	65 SE	50 SE, NNW	55 W	60 SSW	55 WSW	60 SW	60 E,S	45 ESE	24 ENE	

Source: Meteorological Department
Ministry of Communications

Fig. AP 4.21 Simplified soil profile

Location : On-Nooch disposal site

Date : 10 November, 1980



Source : Study team

b. Soils

Generally, soils of metropolitan Bangkok area are composed of clayey soil layers, so called Bangkok clay. To know the actual soil profile of Bangkok city, boring surveys were made at two points in the On-Nooch final disposal site.

Results of the survey clearly indicate the strata as follows: a surface stratum up to 3 meters deep is, in a sense, artificial soil consisting of waste and clay; the second stratum from 3 to 14 meters deep is a clay layer with high consolidation and high moisture content and, underneath, there is about one meter thick medium clay stratum; the deeper stratum up to 24 metets is hard clay or sandy clay layer; from 24 to 30 meters deep, strata consists of very hard clay.

This result is consistent with the already-known general strata of Bangkok metropolis.

The assumed strata between the two boring points are shown in Fig. AP 4.21

Summary of result of the boring survey is shown in Table AP 4.23.

c. Quality of groundwater

Groundwater quality analysis was performed for samples at On-Nooch from a 30-meter deep Bangkok aquifer. The results implied contamination of groundwater with values of approximately 10 mg/L in both BOD and COD. Nevertheless, the permeability coefficient of clay strata at the sampling point was on an order of 10^{-8} cm/s which is geologically regarded impermeable; therefore, theoretically it takes more than 350 years for leachate to permeate through 30-meter thick clayey strata. This means that, considering the number of years since landfill work started, contamination of groundwater probably was not caused by solid waste leachate. However, it is risky to draw such a conclusion from the limited amount of data examined. The results of the analysis is shown in Table AP 4.24.

d. Quality of leachate

Quality of leachate investigated at On-Nooch landfill site is shown in Tables AP 4.25 and 4.26.

Leachate sampled at the foot of landfill slopes shows lower values in many analysis items than that sampled from inside the landfill site because of dilution with rainwater, but the value of COD at the foot of the landfill slope is higher than from inside the landfill site. Both samples show a tendency to have COD >BOD. This means that leachate has been stabilized to the extent over that further biological treatment will be ineffective. Leachate is brown

Table AP 4.23 Physical composition of soil layer

Location On-Nooch Disposal site

Date of sampling October 15, 1980

Depth m	Moisture content (%)		Wet unit weight (t/m^3)		Dry unit weight (t/m^3)		Liquid limit (%)		Plastic limit (%)		Specific gravity		Porosity	
	B-1	B-2	B-1	B-2	B-1	B-2	B-1	B-2	B-1	B-2	B-1	B-2	B-1	B-2
3.0 - 13.5	74.3	77.1	1.66	1.60	0.97	0.92	60.8	61.0	29.5	29.0	2.69	2.71	0.74	0.72
13.5 - 15.5	29.5	22.0	1.99	1.89	1.52	1.55	64.0	63.9	31.5	28.6	-	2.70	-	0.41
15.5 - 20.0	37.2	28.4	1.86	1.91	1.36	1.51	65.0	35.3	31.7	21.6	-	-	-	-
20.0 - 24.0	21.9	17.3	1.92	2.06	1.58	1.76	36.0	-	21.6	-	-	-	-	-
24.0 - 27.0	20.3	20.7	1.94	2.01	1.61	1.67	-	43.2	-	24.8	-	-	-	-
27.0 - 30.0	17.0	14.0	1.99	2.05	1.70	1.79	-	-	-	-	-	-	-	-
30.0 - 35.0	20.8	18.0	2.06	2.05	1.70	1.74	-	42.5	-	24.0	-	-	-	-
35.0 - 40.5	14.1	13.8	2.05	2.02	1.80	1.78	-	-	-	-	2.70	2.69	-	-

Note: Figures in the table show mean value of the samples taken from each layer.
Source: Field Investigation Report

Table AP 4.24 Quality of groundwater

Location: On-Nooch

Sampling: 30 m - deep from ground surface

Parameters		Nov 3, 80	Nov 18, 80
pH		6.45	6.30
BOD	mg/L	9.22	0.00
COD			
$KMnO_4$,	mg/L	11.10	9.50
K_2Cr_2O	mg/L	518.00	360.00
SS,	mg/L	6.00	45.00
CN^- ,			
Alkyl-Hg,	mg/L	0.01	0.02
Total-Hg,	mg/L	0.07	0.05
Cd	mg/L	ND	ND
Organic phosphorus Comp.			
- Methyl dimethone			
- Methyl parathione		ND	ND
- Parathione, EPN		ND	ND
As,	mg/L	ND	0.05
Cr^{+6},	mg/L	ND	ND
Pb,	mg/L	0.18	0.05
PCB,		ND	ND
n-Hexane Extracted			
matter,	mg/L	ND	ND
Phenols,	mg/L	0.01	
Cu,	mg/L	0.75	ND
Zn,	mg/L	4.50	3.00
Fe (dissolved),	mg/L	16.00	22.50
Mn (dissolved),	mg/L	2.00	4.00
F^-,	mg/L		
Cr-AA,	mg/L	ND	ND
- Colorimetric,	mg/L	ND	ND

Source: Field investigation report

coloured with humus-like materials. Dissolution of heavy metal into leachate is small and negligible; this is a specific character of leachate.

Table AP 4.25 Analysis of leachate (average in rainy and dry seasons)

Location: On-Nooch landfill site

Analysis item	Foot of landfill slope point-1		Foot of landfill slope point-2	
	Rainy season	Dry season	Rainy season	Dry season
pH	8.25	8.33	8.00	7.55
BOD (mg/L)	39.70	48.17	47.75	47.80
COD ($KMnO_4$) (mg/L)	350	648	392	902
SS (mg/L)	515	71	395	28
Pb (mg/L)	0.30	0.13	0.14	0.08
Fe (soluble) (mg/L)	4.27	5.65	2.88	7.15
T-N (mg/L)	141.5	123.7	139.6	212.7
NH_3-N (mg/L)	71.9	61.6	78.0	155.3
NO_3-N (mg/L)	8.50	2.68	1.83	2.39
Cl^- (mg/L)	1,615	1,630	1,720	1,817
Sulfide (mg/L)	3.68	3.30	3.98	4.38
Coliform (N/mL)	365	651	290	368
Evaporation Residue (mg/L)	4,885	7,620	7,805	10,140
Ignition Loss (mg/L)	1,305	1,803	1,410	1,873

Source: Field investigation report by the Study team

Table AP 4.26 Analysis of leachate with a level of significance of 5%

(Unit: mg/L)

Sampling point	pH	BOD	COD	Fe (soluble)	T-N
At foot of slope point-1	8.09-8.55	24.3- 65.3	0-1,173	0 - 10.19	0-4,038
At foot of slope point-2	7.50-7.96	27.3- 68.3	54-1,342	0.34- 10.54	0- 456
Inside mound point-1	8.22-8.68	147 -189	606-1,894	5.5 - 15.7	1,357-1,903
Inside mound point-2	8.25-8.71	354 -396	2,576-3,864	54 -642	1,467-2,013

Sampling point	NH_3-N	NO_3-N	Cl^-	Evaporation residue	Ignition loss
At foot of slope point-1	0-187.7	0-42.81	1,309-1,939	4,699-8,361	950-2,250
At foot of slope point-2	2-246	0-39.97	1,465-2,095	7,379-9,210	1,040-2,340
Inside mound point-1	912-1,156	6.9-82.5	2,045-2,675	10,369-14,031	1,380-2,680
Inside mound point-2	988-1,232	565-1,321	3,555-4,185	21,729-25,391	5,470-6,770

Appendix 4.11 Estimates of remaining capacity of the existing landfill sites

Table AP 4.27 Remaining capacity of the existing landfill sites

Landfill Site	Total site area	Landfill method	Remaining landfill capacity by cases.						Remark
			Case - 1		Case - 2		Case - 3		
			Zone	capacity (m^3)	Zone	capacity (m^3)	Zone	capacity (m^3)	
On-Nooch	928,920 m^2 (581 rai)	Flat land (+3.00m)	A + B + C	1,477,100	A + B	302,600	A + B	302,600	Ground of A-zone is under excavation, therefore, landfill ground level is assumed - 2.00m.
		Mound (+15.00m)	D + E	1,682,100	(D + E) + C	5,340,300	(D + E) + C + (F + C)	7,939,400	Already disposed of volume in D-zone is estimated 694,700 m^3
			Total	3,159,200		5,642,900		8,242,000	
Nong Khaem	588,060 m^2 (368 rai)	Flat land (+3.00m)	A + B + C	911,800	A + B	239,300	B	37,000	
		Mound (+15.00m)	D	2,283,700	D + C	5,038,700	(D + C) + A + E	6,175,400	Already disposed of volume in D-zone is estimated 444,900 m^3.
			Total	3,195,500		5,278,000		6,212,400	
Tung Kru	64,000 m^2 (40 rai)	Flat land Mound	9,600 m^3 460,000 m^3						Already disposed of volume is estimated 88,200 m^3.
Ram Intra	80,000 m^2 (50 rai)	Mound (+15.00m)	696,600 m^3						Adjoining open space for site extension.
Bung Tanode	8,000 m^2 (5 rai)	Mound (+10.00m)	32,700 m^3						
Bung Phrayasalum	8,000 m^2 (5 rai)	Flat land (+3.00m)	24,000 m^3						
Total			7,577,600 m^3		12,143,800 m^3		15,677,300 m^3		

Fig. AP 4.22 On-Nooch final disposal site

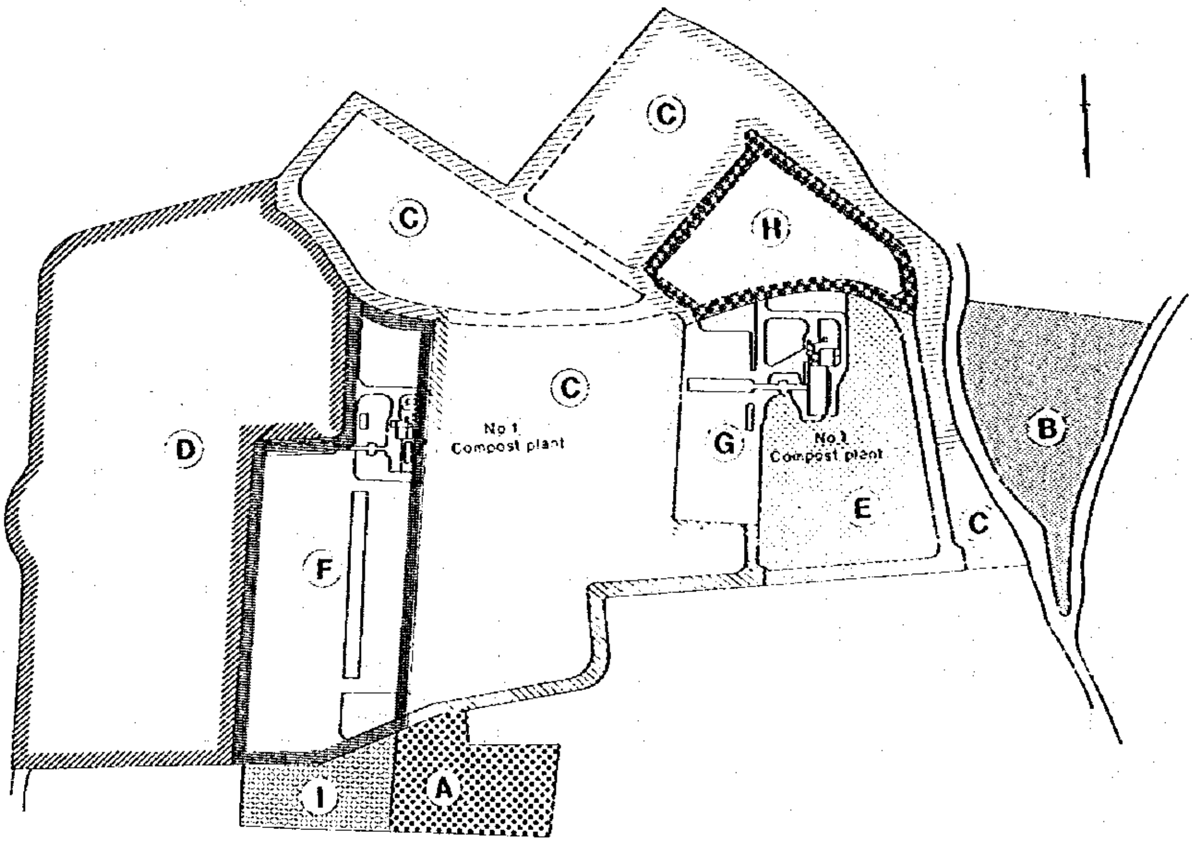
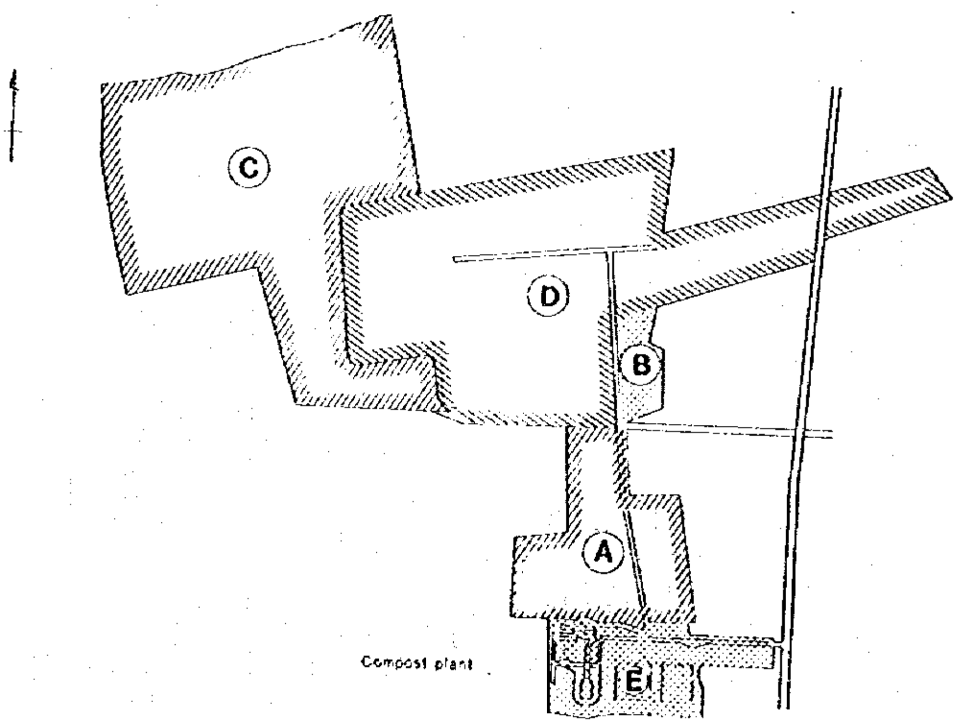


Fig. AP 4.23 Nong Khaem final disposal site



Appendix 4.12 Intermediate treatment facilities sites alternatives

Fig. AP 4.24 Examined location of the intermediate treatment facilities construction sites alternatives

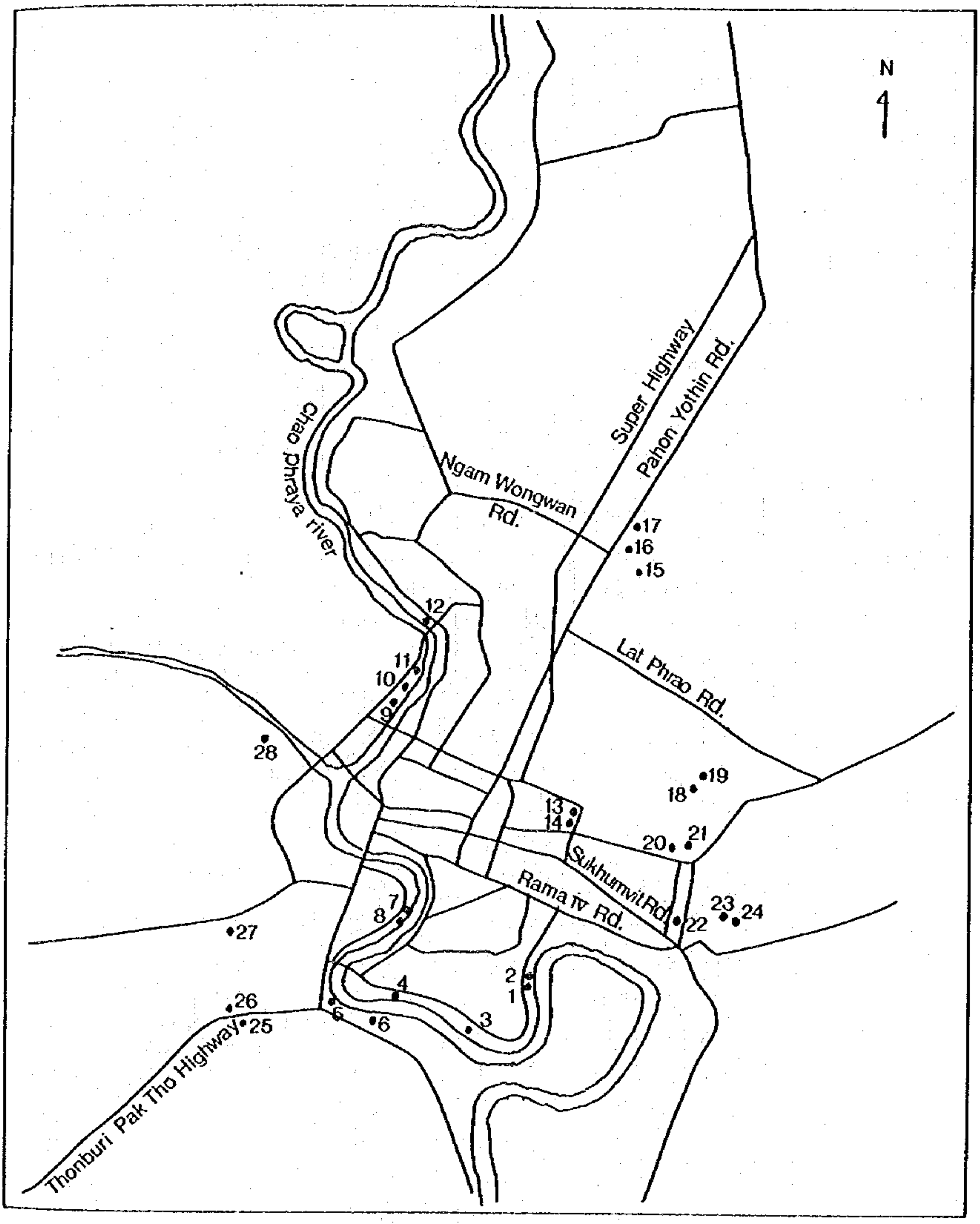


Table AP 4.28 List of examined intermediate facilities construction sites

No.	Computer code No.	Zone No.	District name	Vacant land area (m^2)	Possible treatment capacity (t/d)	Remark
1	701	6	Yannawa	30,000	1,200	The area will be selected among these alternatives.
2	701	6	Yannawa	38,400	1,200	
3	-	7	Yannawa	89,000	-	Developed area
4	702	7	Yannawa	120,000	1,200	
5	-	41	Rat Burana	8,800	-	In the high density mixed use area
6	711	41	Rat Burana	37,500	800	
7	-	33	Khlong San	38,000	-	In the high density mixed use area
8	-	33	Khlong San	16,000	-	"
9	-	34	Bangkok Noi	16,600	-	"
10	-	34	Bangkok Noi	14,000	-	"
11	707	34	Bangkok Noi	43,000	960	"
12	703	9	Bang Khen	59,000	1,200	
13	-	10	Phayathai	37,000	-	In the high density mixed use area
14	-	10	Phayathai	25,000	-	"
15	712	19	Bang Khen	12,000	1,200	The area will be selected among these alternatives.
16	712	19	Bang Khen	22,000	1,200	
17	712	19	Bang Khen	80,000	1,200	
18	705	13	Huai Khwang	55,000	1,200	The area will be selected among these alternatives.
19	705	13	Huai Khwang	23,000	1,200	
20	704	12	Huai Khwang	85,000	1,200	The area will be selected among these alternatives.
21	704	12	Huai Khwang	200,000	1,200	
22	706	14	Phra Khanong	28,000	1,200	The area will be selected among these alternatives.
23	706	14	Phra Khanong	9,600	1,200	
24	706	14	Phra Khanong	18,000	1,200	
25	709	37	Bang Khun Tian	10,800	1,200	
26	709	37	Bang Khun Tian	15,000	1,200	
27	710	39	Phasi Charoen	12,000	1,200	
28	708	35	Bangkok Noi	25,000	1,200	