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management of solid wastes in developing countries

by Frank Flintoff

WORLD HEALTH ORGANIZATION
Regional Office for South-East Asia

PREFACE TO THE SECOND EDITION

This second edition has been published in response to the continuous flow of requests received by WHO from various developing countries, not only within WHO's South-East Asia Region, but other regions as well. The publication has justified the hope expressed in the original Foreword that it "will be used widely and that it will be recognized as a contribution to an aspect of environmental health which has perhaps received inadequate attention in the past".

Although the first edition was prepared more than eight years ago, relatively few changes have had to be made in the new edition since much of the text and concepts of appropriate technology included in the original edition are perfectly valid even today. It is hoped that the new edition will continue to serve as a reference source for practitioners and for those receiving introductory training in this field.

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Dr U Ko Ko
Regional Director

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CHAPTER 1
INTRODUCTION

At all levels of development human beings produce domestic wastes: at the very minimum these comprise kitchen wastes, ashes from fires, broken utensils and wornout clothing. In a small agricultural community nature readily accepts these wastes into her natural cycle: animals consume food residues, and other materials are rapidly incorporated into the soil.

The industrial revolution in the temperate countries concentrated people in urban areas of very high population density and added new sources of wastes: shops, institutions and factories. Apart from any question of public health it was impossible to accommodate these wastes, arising at a rate of up to one ton/family/year, within the urban areas. Thus, in those countries where industrialization came early, services for the regular removal of domestic and trade wastes have been in operation for a hundred years or more.

Many changes have taken place during this period: the character of the wastes has altered in line with rising living standards, changes in retail distribution methods and fuel technology. The volume has greatly increased; storage methods have evolved from open heaps through portable containers to expendable containers; transport has changed from horses to motor vehicles and from open trucks to compactor vehicles. New problems have arisen—high-rise buildings, supermarkets, industrial wastes of many kinds—and usually efficient solutions have been devised.

At this stage in their development, most industrialized countries exhibit the following common features:

- a high level of national wealth which is still increasing;
- a taxation system which provides a reliable source of funds for public services such as refuse collection;
- a long tradition of regular and efficient removal of refuse direct from dwellings and other premises, and usually operated by a municipality;
- a high level of sensitivity to aesthetic standards within private premises (which does not always extend to standards in public places);
- willing acceptance by householders, shopkeepers and others of statutory duties such as providing and maintaining storage containers, sometimes of a specified type and size, and assisting in making

— quality of management and technical capacity,
— the environmental standards required.

It was against this background that the Bangkok Seminar stressed the importance of the following issues:

— protection of health and the environment at a level of cost that can be sustained locally,
— development of systems based on local climatic, physical, economic and social factors,
— production of efficient, indigenous tools and equipment,
— the achievement of high productivity from labour and equipment, especially motor transport,
— education of the public,
— vocational or professional training for middle and top management.

This manual is aimed at both the latter groups. It was initiated by the Government of India to satisfy a need which was first voiced as a recommendation of a WHO expert committee (Solid wastes disposal and control, *WHO Technical Report Series* No. 484):

"The function of the technician is the day-to-day supervision of refuse collection and disposal, which requires thorough training in applied technology and administration."

This recommendation was echoed by the Bangkok Seminar:

"A solid wastes technician's course should be a five to ten month course and should include characteristics and analysis of wastes, equipment, systems, planning and operation of street cleansing, refuse collection, refuse treatment plants and disposal systems, vehicle maintenance, stores and inventories and manpower management. An important requirement is the preparation of a manual or manuals covering the suggested syllabus in terms of regional or national need."

1.1 Sources and characteristics

"Solid wastes" is the term now used internationally to describe non-liquid waste materials arising from domestic, trade, commercial, industrial, agricultural and mining activities, and from the public services. "Non-liquid" is a relative term because sludges of certain kinds fall within the scope of solid wastes management; these arise primarily from industrial sources and from sewage treatment plants.

Solid wastes comprise countless different materials: dust, food wastes, packaging in the form of paper, metals, plastics or glass, discarded clothing and furnishings, garden wastes, construction wastes, factory offcuts and process wastes, pathological wastes, and hazardous and radioactive wastes.

Domestic wastes have three main characteristics: weight generated, density and constituents; these vary not only from country to country, but

Institute, India, has carried out studies that show a higher incidence of intestinal parasites in collectors of domestic wastes than in the population as a whole.*) There are also specific risks in handling wastes from hospitals and clinics.

For the general public, the main risks to health are indirect and arise from the breeding of disease vectors, primarily flies and rats. Improper storage and disposal provide the conditions under which these risks arise.

The most obvious environmental damage caused by solid wastes is aesthetic: the ugliness of street litter and the destruction of the beauty of the countryside by uncontrolled dumping of city wastes. More serious, however, and often unrecognized, is the transfer of pollution to water, which occurs when the leachate from a refuse dump enters surface water or groundwater. Air pollution can be caused from the inefficient burning of wastes, either in the open air, or in plants that lack effective treatment facilities for the gaseous effluents.

Industrialization introduces dangers of a different kind: hazardous wastes from industry present risks during transport and disposal. Traffic accidents can result from toxic spilled wastes: they have caused death and injury to people in the vicinity. Improper disposal of such wastes has resulted in the death of humans and animals through contamination of crops or water supplies.

Finally, there is the specific danger of the concentration of heavy metals in the food chain, a problem that illustrates the relationship between solid and other wastes. It has sometimes happened that liquid industrial effluents containing heavy metals have been discharged to a drainage system and have contaminated the sludge leaving the treatment plant. These metals can be taken up by the plants growing on land on which sludge has been deposited, creating risks to the animals which graze and the humans who consume the animals.

1.3 Economic implications

Labour and transport absorb the major part of the operating costs of solid wastes management services. It is usual for a city to employ between two and five workers for each 1 000 population. Three workers/1 000 population may represent about 1% of the total national workforce. Transport is required on a scale of about 1 heavy vehicle/15 000 population. Thus, solid wastes management services can absorb up to 1% of the gross national product, and are one of the most expensive city services. Efficiency of systems and high labour productivity, therefore, are of vital importance.

The level of mechanization that should be adopted for solid wastes management systems relates directly to the cost of labour, as compared to that of plant and energy. There is not much variation, worldwide, in energy

* Short-term study of health status of refuse workers at Trivandrum, NEERI Report, 1970.

CHAPTER 2
SAMPLING METHODS

2.1 Generation

The generation of solid wastes varies in different types of dwelling as well as in different socio-economic groups.

2.1.1 Generation in relation to collection and disposal The following are the methods commonly used to estimate the total quantity of wastes to be collected and disposed of:

- — average loads collected/day multiplied by average volume/load ascertained by measuring a vehicle body, and converted to weight by using an average density obtained by sampling,
- — sample vehicle weighings, using a weighbridge, the average being multiplied by the total loads/day.
- — weighing of every load on a weighbridge at the disposal site; this is the only accurate method.

Measurement of the total weight of wastes delivered to a disposal site, however, is seldom an accurate indication of wastes generated, as distinct from wastes collected, because of losses at various stages. The following may be a typical pattern:

Stage	*Handling phase*	*Losses*
	Total Generated	
1		minus salvage sold by householder
2		salvage by servants
3		salvage by scavengers
4		wastes disposed of by unauthorized means, e.g., on unused ground or in ditches.
	Total Collected	
5		minus salvage by collectors
	Delivered for Disposal	
6		minus salvage by disposal staff
		salvage by scavengers
	Total Disposed of	

After selection of the sampling areas, each householder should be interviewed, to explain the purpose of the sampling project. It is desirable that this be done by social workers who are better trained in communication. An explanatory leaflet should be left at each dwelling.

The sampling programme should extend over eight successive days. Wastes collected on the first day should be discarded as the period they represent may be doubtful; wastes collected from the Second to the Eighth day will represent one week's production.

The collector should carry a supply of plastic bags, one of which should be handed in at each dwelling in replacement of the full one collected. Each full bag should be labelled with its appropriate classification before being taken to the depot where the contents are weighed and the volume measured.

For calculation of the total weight and volume generated in the city, a multiplier is used for each coded group based on the proportion of the population represented by that group. For example, if the A.1 sample is from 600 persons and the total population in that classification is 40 000, then the multiplier would be 66.7.

In most cases, samples collected in this way would also be used for physical analysis, as described in the succeeding section, supplemented by samples representative of trade and commercial wastes.

The labour requirement for a programme of this kind is as follows:

Total calls/day for 1 200 dwellings		1 200
Calls/collector @ 20 calls/man/hour for 6-hour day		120
Number of collectors required per day		10
Period for which required	days	8

(A basic weakness of this method of estimating generation is that, despite explanations given in advance, the householder may vary the normal pattern of wastes disposal for personal reasons if he or she knows that the wastes are going to be examined. Greater accuracy is assured when samples can be obtained without the knowledge of the householder; this applies in Britain, where the sampling collectors simply move in a little earlier than the normal house-to-house collectors. This is not practicable, however, in cities where the main storage methods are communal.)

2.1.4 Collection of samples from communal containers For many purposes such as deciding the design of refuse collection vehicles and the method of refuse disposal, collection of samples direct from source is unnecessary, and samples can be taken from communal containers or transfer stations. This is a much simpler procedure and requires merely the daily collection of at least 12 samples, each at least 200 kg or 500 litres, from areas which properly represent the selected socio-economic groups and trade sources.

The density of samples collected in this way will be higher than that of samples collected direct from source because the density of the wastes increases at each stage of handling, partly through the removal of light constituents such as paper, and also by compaction of material at low level on this screen are now hand–sorted until only vegetable/putrescible matter remains; this is the 10 mm-50 mm size.

By this time the wastes are completely sorted into the required constituents and sizes except that the fine matter below 10 mm will be a mixture of inert and organic matter, such as sand and food grains. The proportions can be established only in a laboratory by moisture and ignition tests, but with experience it is possible to make a fairly accurate estimate by visual examination.

2.2.3 Information from analysis The following example of a summary sheet shows the kind of information needed:

Constituent	*Sample No. and % by Weight*							
	1	2	3	4	etc	Max	Min	Average
Vegetable/putrescible matter								
above 50 mm								10
10 mm – 50 mm								35
below 10 mm								10
Total								55
Paper								15
Metals								5
Glass								4
Textiles								3
Plastics & rubber								2
Bones								-
Misc. combustible								2
Misc. incombustible								4
Inert matter below 10 mm								10
TOTAL								100
DENSITY kg/cu.m								350
SOURCE OF SAMPLE	code letter							

2.2.5 Projections Analyses are often made as part of feasibility studies for refuse treatment such as composting and incineration. Such plants have lives of twenty years or more, and in such cases it is vital that the design parameters should be based on projected and not current analyses if performance is to be reasonably uniform throughout the working life of the plant.

Over a long period it is likely that changes occur in the physical characteristics of wastes, from the following causes:

— a rising standard of living increases the production of solid wastes, particularly constituents other than vegetable/putrescible matter,
— changes in packaging technology and retail distribution methods tend to increase packaging materials and volume per capita,
— changes in domestic fuels, for example a reduction in the use of solid fuel, could cause falling ash content and a reduction in weight per capita.

In cities where annual analyses have been carried out for 15 years or more, changes of this kind appear on a graph as a smooth curve from which it is usually possible to extrapolate estimated analyses for up to ten years ahead. Where such information does not exist, it is possible to make projections based upon national and local forecasts of economic growth and industrialization.

Almost without exception communal containers cause problems: they were sometimes overfilled, or refuse was thrown around them; they were disturbed by birds, dogs, cattle, and pigs as well as scavengers searching for saleable materials. Official sites were often supplemented by random heaps on verges.

Trucks used for collection from communal sites were usually open bodies on standard commercial chassis without tipping gear. Loading was a tedious process of filling baskets, carrying them to the vehicle and handing them to a man inside it. Hand unloading took a long time and caused congestion of vehicles at the disposal sites.

3.2 House-to-house collection

House-to-house collection is a comparative rarity and standardized bins were never seen. In Colombo and parts of Jakarta the bin is usually improvised from an oil drum or a similar container. Often the bins are kept permanently on the verge outside the house, even when there is space in a garden. In Bangkok baskets and plastic bins are used and are put outside only during the period when a kerbside collection is expected.

Vehicles used in Colombo, Rangoon, Central Delhi and Bangkok are

2. Manually portable communal container used for a group of dwellings in central Rangoon

3.4 Recycling

Throughout the Region, labour-intensive recycling operates on a vast scale. Householders keep newspapers, bottles, etc., separate and sell them to collectors. Communal bins are searched by scavengers and the process is continued by refuse collectors and disposal site scavengers.

3.5 Problems of storage and collection

The large numbers of open communal storage sites and unofficial dumps encourage the breeding of flies and rodents.

Methods of collection often result in workers being exposed to regular skin contact with wastes which sometimes contain faecal matter. This may be the cause of the higher incidence of certain diseases found by NEERI to occur among refuse collectors.

Almost everywhere in the Region motor vehicles are too old and too few in number. This problem is a compound of poor maintenance and the frequent lack of a vehicle replacement policy supported by a sinking fund.

The work of refuse collection vehicles other than hand-carts is impeded in many cities by dense traffic in the city centre. In most of the large cities there are certain areas where the roads are too narrow to admit motor vehicles. The solution to this problem, which has been adopted at Bangkok, is for single collectors to take a basket on a trolley down the lanes and to stack the full baskets in the nearest main street where they are emptied into motor vehicles. It is not uncommon, however, for the residents of these alleys to be ignored, causing rotting accumulations in yards or on the banks of streams.

In most of the Region there was some evidence of public dissatisfaction with refuse collection services; equally many officials complained of lack of co-operation from the public.

3.6 Constraints

Solutions to these problems have to be sought within the limitations imposed by a number of constraints. The most important single factor is whether the community can afford to pay for a good standard of service.

Most of the cost of refuse collection is incurred in the form of manual labour and motor vehicles. Asia has the advantage of low wage rates and it is reasonable to suggest that the cost of manual labour can be sustained. Motor vehicles, however, present a formidable problem. Imported vehicles may have a relative cost, in terms of GNP/head, twenty times that of Europe*. Even when it is desired to import vehicles, this may not be possible because limited foreign exchange is required for more important services.

*For example, a vehicle costing US $ 20 000 in a country with a GNP/head of $ 4 000 requires 5 man-years to pay for it; in a country with a GNP/head of $ 200 the number of man-years absorbed is 100.

CHAPTER 4
ELEMENTS OF REFUSE COLLECTION

4.1 Refuse characteristics and sources

The generation of domestic and trade wastes is a remorseless and continuing process. Throughout the day a housewife is performing such tasks as sweeping floors and trimming vegetables; the shopkeeper is discarding packing materials and spoiled goods; the shoemaker is paring leather; almost every member of the population is continuously creating wastes of one kind or another. In the case of human body wastes, a sewage system provides facilities for transfer from the production point to the disposal place by a continuous flow process in pipes containing water. Despite the successful use of pneumatic transfer in underground pipes at a few residential developments in Europe, no such method is generally practicable for solid wastes. Thus refuse collection must be a batch process, or a series of batch processes, whereby wastes are stored at the point of origin for a given period, before being transferred to a vehicle, the contents of which represent one batch of many arriving each day at the disposal point.

The main sources of those solid wastes for which a municipality normally assumes responsibility are domestic premises, shops, offices, hotels, institutions, and small factories, together with refuse swept from the streets. Domestic wastes often account for about 75% of the total.

The main constituents of solid wastes are similar throughout the world, but the proportions vary widely from country to country and even within a city, because the variations are closely related to income levels. The analyses on the next page, carried out in accordance with the systems described in 2.2.3, show this relationship very clearly. The figures relate to two specific cities and are not national averages. All weights include initial moisture content.

As personal income rises, paper increases, kitchen wastes decline, metals and glass increase, total weight generated rises and the density of the wastes declines.

There are often local variations in wastes generation and constituent proportions over weekly and seasonal cycles; the former is related to the pattern of work and leisure and the latter to seasonal food products and sometimes to fuel residues arising from space heating in winter.

— travel to and from the work area;
— the collection process, which includes: transfer of the wastes from storage to the vehicle and travel between successive collection points;
— the delivery process whereby the contents of the vehicle are transported to the disposal site.

During non-working hours vehicles will be kept at a depot with enclosed parking space. The distance between the depot and the collection area should be kept to a minimum because time spent travelling is unproductive. In the case of motor vehicles this requirement may have to be balanced against the need to centralize facilities for maintenance and stores, particularly fuel supplies, and to centralize the allocation and control of drivers and vehicles.

The slower speed of animal carts and handcarts requires the provision of closely spaced district depots, and these are also much more efficient for the control of the collectors, who can book on and off within a short distance of the area where they will be working.

The many methods of transferring wastes from storage to a collection vehicle fall into three main categories:

— the direct emptying of a portable storage container into the vehicle, normally used when the vehicle can be positioned close to the containers;
— the emptying of a portable storage container into a transfer container (usually a large basket) which is then emptied into the vehicle, normally used when the storage container is some distance from the vehicle, in order to avoid the return walk with the empty container;
— the transfer of wastes stored at ground level, which usually requires that the wastes be raked or shoveled into the vehicle.

These three categories have been set out in ascending order of work content. Thus the first is the most efficient in terms of labour and vehicle productivity; it is also the method that minimizes human contact with the wastes.

Travel between successive collection points depends first upon the spacing. When these are some distance apart, as with large communal storage sites, travel by motor vehicle, although it represents lost time, will be at normal road speed and the collectors will ride on the vehicle. It is thus an efficient method of transporting the workers between sites.

When collection is from house to house, however, the collectors will walk the short distances between containers and the vehicle will move slowly and at intervals. For this element of travel the motor vehicle is very ineffectively employed; it incurs heavy transmission wear and high fuel consumption. Handcarts and animal carts are much more efficient: they operate at their optimum speeds and no energy is used while they are stationary.

For collectors walking from house to house, the distance to be walked is proportional to the number of men in a team. One man alone walks from one house to the next; in a three-man team each man collects from every third house, thus labour productivity declines as team size increases. Vehicle productivity, however, increases with team size as it is loaded more quickly.

The delivery process, when a full vehicle travels at normal road speed from the collection area to the disposal site, represents maximum productivity for the vehicle, but lost time for the collectors if they accompany it. Handcarts and animal carts are very inefficient for this operation because of their slow speeds and limited capacity.

The following conclusions can now be drawn:

— minimum physical infrastructure requirements are a central workshop with parking space for motor vehicles, and district depots for mustering and controlling collectors, handcarts and animal carts; the locations of depots should minimize travel time between depot and working area;
— systems which provide for the direct emptying of portable storage containers into a vehicle offer the highest productivity and the lowest health risks to workers;
— for the collection of wastes direct from houses, large teams give low labour productivity and higher vehicle productivity;
— handcarts and animal carts may be more efficient than motor vehicles for the house-to-house collection phase;
— motor vehicles are the most efficient for transport of complete loads from the collection area to the disposal site.

Figure 1 is a flow chart of the refuse storage and collection process and indicates the main areas of decision which will be discussed in succeeding chapters.

5.2 Collection direct from premises

The character of a dwelling or shop exerts a strong influence upon the frequency of collection. The house which stands in a garden, or the shop with an open storage area behind it, rarely has any problems in the storage of wastes in enclosed containers for periods of up to a week. There are large areas of USA which have a sub-tropical climate and where weekly collection is quite common, but this is acceptable only because two conditions are satisfied: space for storing the container in the open air and the provision of containers with well-fitting lids which prevent emission of odour as well as access by insects.

At the other extreme is the small apartment where the only space in which a wastes container can be sited is in the working area of the kitchen. Aesthetic standards and space limitation combine here to impose a maximum storage period of 24 hours. In such conditions it is necessary to provide a daily collection from each apartment, or to provide a communal container.

Small lock-up shops and large markets with rented stalls present a similar problem: a daily collection is necessary for the former, while market stalls may need to be visited several times a day.

In developing countries the population density of large areas of the major cities is much higher than in the industrialized countries and in these areas external sites for home storage of wastes will usually be lacking; collection frequency, therefore, will often have to be daily.

The extent to which statutory duties are imposed upon residents may affect frequency of collection. Where there is a duty to place the domestic container at the kerbside, frequency must be high enough to limit the weight and size of the container to the capacity of an old person. Where a "block collection" is operated (whereby residents have to deliver their wastes to the vehicle, which stops for a short time at each road intersection) the constraint on weight and volume assumes greater importance because of the longer distance the wastes have to be carried. The maximum interval for this system is often two days.

5.3 Cost

For the collection of wastes direct from premises, cost/ton rises rapidly as frequency of collection is increased. This is because the main determinants of the work content of a collection route are the number of containers to be emptied and the distance to be walked between them. These factors are almost constant for frequencies between one and seven days. What does vary is the weight in the container, and hence the greater the frequency the less the weight collected and the higher the cost/ton. This is illustrated by the following productivity data for two American cities, one collecting weekly and one twice weekly, using similar systems*.

* Adapted from "Residential Collection Systems" (EPA, 1975); from much other data the authors conclude: "Increasing the frequency from once a week to twice a week required approximately 50% more crews and equipment..."

CHAPTER 6
REFUSE STORAGE METHODS

6.1 Domestic premises and shops

The storage volume which it is necessary to provide for domestic wastes is a function of generation, family size and frequency of collection. Based on six persons/family, the probable range required in S. E. Asia is as follows:

Collection frequency	*Minimum volume* (litres)	*Maximum volume* (litres)
Daily	4	10
Twice weekly (maximum 4 days)	20	50

The following types of storage containers are available in most countries:

— *plastic buckets with lids* have capacities from 7 to 10 litres, sufficient for the domestic wastes of a family of six for a daily collection.
— *plastic bins with lids*, having capacities from 20 to 30 litres, with steel drop-down semicircular carrying handle, or a rectangular handle which allows the lid to be lifted, but prevents its removal, are suitable for a twice weekly collection for the majority of dwellings in S. E. Asia.
— *galvanized steel, or plastic bins with lids*, capacity 50 to 70 litres, are necessary when collection is twice weekly from a high income group, or for daily collection from shops. Bins of this size are relatively more expensive than smaller sizes because, if they are to give long service, they should be manufactured to a high specification. Steel bins should be galvanized after manufacture by hot dipping, not made from pre-galvanized sheet which rapidly corrodes at the rivetted seams. Plastic bins of this size should be of high-density polythene or plastics of similar characteristics.
— *expendable plastic* sacks have a number of obvious advantages but in Asia, where annual expenditure/family on refuse collection may be

at which householders deposit their wastes evolve or are imposed. These communal storage sites are a nuisance to the people who live adjacent to them, but they could be eliminated only by the universal use of household bins, a solution which may not be practicable in some areas. In their attempts to alleviate the problems of communal storage, local authorities throughout the world have devised many different methods of partially or wholly enclosing wastes:

— depots, known as "dalaos",
— enclosures of timber, steel, brick or concrete,
— fixed storage bins,
— concrete pipe sections,
— 200–litre drums,
— portable steel bins.

6.2.1 Depots Depots which consist of a single-storey building about the size of a large garage, or the ground floor of a multi-purpose building, are commonly used for the storage of wastes at large markets; they have also been adopted for the storage of domestic and trade wastes in a number of Asian cities. Delhi, for example, has about 150 of these buildings, some of which have rooms above, which house manual or supervisory staff. Many are sited on the perimeter of the densely populated walled city, and the wastes are delivered to them, through a maze of narrow lanes, by residents, shopkeepers, sweepers and private collectors. The capacity of such a depot, which has a concrete floor and often tiled walls, may be as great as 25 cu.m, but the average throughput in Delhi is about 12 cu.m/day, probably equivalent to a population of 10 000 or more at the present local rate of generation. Thus, such large storage places are suitable only for areas of very high population density, otherwise the distance between them would be far too great. Even a density of 40 000 persons/ km^2 implies an average walk of 150 metres if storage places of this size are perfectly spaced, which is unlikely to be possible.

Such depots do, however, solve some of the problems normally associated with communal storage:

— the wastes are protected from rain;
— domestic animals and scavengers can be prevented from gaining access to them because the size of the installation is sufficient to justify placing a labourer to exercise continuous control over it.

The most difficult problem, and one that has to be squarely faced, is that of acquiring sites for storage depots; the area occupied by those described is equivalent to a large shop, and the location must be on a road wide enough for vehicle access. Such sites are often very costly to acquire.

The major criticism of the depots that have been observed is the manner in which they are operated: usually all wastes are dumped on the ground, and thus the process of collection involves filling baskets which are then carried to a vehicle. This is a dirty and unhealthy procedure for the collectors, who are brought into close and continuous contact with the

6.2.3 Fixed storage bins This type of container is usually built from concrete blocks. It differs from the screened enclosure by having no entrance: the walls are of a suitable height for wastes to be dropped inside over the wall (1.2–1.5 m.). Capacity is rarely more than about 2 cu. m. In one wall an opening, covered by a flap, is provided through which the wastes are raked out by the collectors.

Similar structures of steel, rectangular or cylindrical, have been observed, the smallest ones, of about 300 litres, having hinged lids on top and an extraction opening at the bottom. These latter go a long way towards meeting the main objections to communal storage: animals, insects and rain are excluded; not scavengers, however.

The real objection to all these containers is the extraction by rake through an opening at ground level. If the material was free-flowing like coal this would work well, but wastes tangle together and in practice it is often impossible to remove them through a relatively small aperture in the way the designer intended: the collectors have to climb inside and fill their baskets from the top of the heap, thus exposing large areas of their bodies to contact with the wastes. It has also been observed that flaps covering the bottom opening tend to break off and disappear, so that the contents overflow at that point. This encourages people to dump their wastes on top of the overflow and the result is storage by the side of the container, not inside it.

6.2.4 Concrete pipe sections One of the problems of communal storage is that of balancing storage volume, which is a function of population density, against an acceptable walking distance for residents. It is reasonable to assume that unless sites are spaced at a reasonable distance, say about 250 m apart, people will be tempted to dispose of their wastes in an unauthorized location which is nearer to their homes. For areas of low population density, therefore, there is a need for containers of comparatively small volume and low cost. Some cities have adapted short lengths of concrete pipe to this purpose.

The most common size is about one metre in diameter, the length being of similar or shorter dimensions. This provides a volume of about 300 litres when the pipe is placed upright on a pavement or a grass verge. Although such a container is almost indestructible and satisfies the basic need to provide a specific location for wastes, it fails almost every other test:

- the wastes are exposed to view;
- they are accessible to flies, rats, domestic animals and scavengers;
- when the pipes are sited on unpaved surfaces, fly larvae can migrate, pupate and hatch;
- the wastes have to be dug out by means of a short rake. This is very hard work in an uncomfortable position, and puts the worker in intimate contact with the wastes.

6.2.5 200-litre drums It is probable that the type of wastes container which is most widely used throughout the world is itself a waste product:

Where 200-litre drums are used as communal containers the problems spring mainly from human behaviour.

- — wastes are thrown around, not inside;
- — drums are deliberately overturned by scavengers who want to search the contents for saleable materials, or by herdsmen who want to expose the food wastes to their goats.

A possible solution to the latter problem is to attach the drums to a post driven into the ground in such a way that they can be released only by the authorized collector. This was usually successful in Britain during World War II when communal kitchen waste bins were placed in the streets as a source of feed for pigs and poultry.

A few cities have demonstrated that it is possible to use 200-litre drums with reasonable success, and in all these cases the standard of management by the local authority has been very high:

- — the drums have been painted inside with bitumen paint to preserve them and on the outside with high gloss paint in a bright colour;
- — locations have been carefully selected and where necessary paved and provided with partial fencing;
- — excess capacity has been provided to avoid overflow at peak periods of wastes generation;
- — damaged bins are quickly replaced,
- — collection is at a daily frequency.

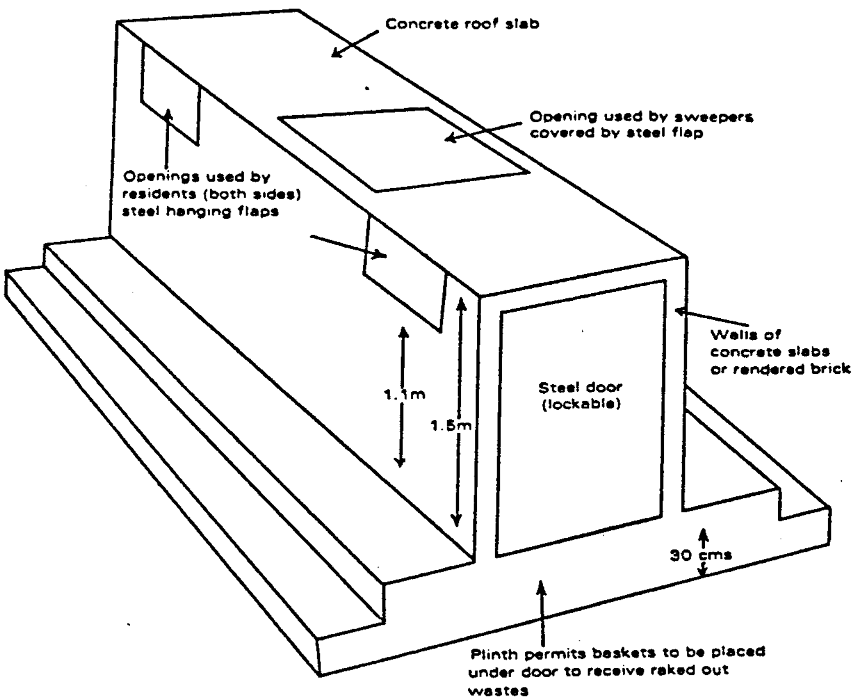
In all these cases the standard of human behaviour was also above average, and this indicates that where local authorities set a high standard of service, not necessarily at high cost, residents respond by co-operating with the system.

6.2.6 Portable steel bins The traditional steel (or plastic) bin of 70 – 100 litres, used in the industrialized countries for domestic storage at home, can also be applied to communal use where generation is low and collection frequency high. Galvanized bins of about 100 litres capacity with well fitting lids, have been observed in the central area of Rangoon, where each serves up to 10 families. This, of course, appears to be the perfect solution in terms of hygienic storage, collection efficiency and the health of residents and workers, but it requires a significant initial expenditure by the local authority and very high standards of human behaviour. The sort of problems likely to be encountered is:

- — loss of bins by theft;
- — failure to replace lids and their subsequent disappearance;
- — interference by men or animals, including mischievous behaviour;
- — traffic accidents caused by bins rolling into the road;
- — two men would be required to lift 100 litres of high-density wastes.

This cannot be recommended as a universal solution, but it may have good

Figure 2 ENCLOSED MASONRY BIN



Dimensions 2m long x 1.5m high x 1.5m wide
Effective capacity 1.8m x 1m x 1.2m = 2cu m approximate

days. Domestic wastes may be more on Sundays than on weekdays. Holidays and feast days may give rise to significant surges in wastes generation.

To avoid containers overflowing, it is advisable to allow up to 50% excess capacity above average generation rate when collection takes place every day of the week. If the collection service operates only six days/week at least 100% over-capacity is necessary to contain 2 days' wastes production.

In the case of communal containers it may be prudent to provide a 100% margin even for a 7 days/week service. Such a policy is particularly helpful where 200-litre drums are used, because the average drum will then be only half full on most of the occasions that it is emptied. This reduces the effort required of the collectors, and it also minimizes exposure of the wastes to view or to interference.

7.1 Basic aims of vehicle design

The following aims are applicable to vehicles of all types:

- the load should be covered during transport; this is imperative for motor vehicles travelling at 30 km p.h. or more, less important for every slow moving vehicles;
- the loading height of vehicles receiving the contents of manually emptied containers should not exceed 1.6 metres;
- unless the load is carried in portable containers, the body of a vehicle should have hand-operated or power-operated tipping gear, or a power-operated ejection plate;
- the transfer of wastes from a primary collection vehicle to a larger vehicle should never involve dumping the load on the ground and both vehicle designs should take account of this;
- there are many situations in which the most suitable vehicle will be a handcart or one drawn by an animal; these vehicles should receive the same standards of mechanical design as motor vehicles, particularly as to ball or roller bearings for wheels, and rubber or pneumatic tyres.

7.2 Handcarts

Handcarts are conventionally used in Europe for street sweepings because they cause minimum obstruction and their capacity is enough to keep a sweeper busy for up to two hours. They are also used in parts of Asia for daily house-to-house collection, especially in very narrow streets inaccessible to motor vehicles. But Asian handcarts are often open boxes, and the only means of transferring the contents to a larger vehicle is to dump them on the ground and use a shovel or a basket for re-loading. This is wasteful of labour and increases vehicle standing-time.

Thus the most important design feature is to ensure that the load is carried in a number of containers which can be lifted off the cart and emptied directly into a larger vehicle. This requirement can be met by constructing the cart in the form of a light framework of tubular steel or angle with a platform on which four or six bins of about 70 litres volume can be carried. In Mexico handcarts are used that comprise a platform supported by four small wheels and carrying two 200-litre (oil) drums, but a problem with containers of this capacity is that two men are needed to empty the drums into a vehicle.

For the daily collection of refuse house to house, one 6-bin handcart load would be sufficient for about 50 dwellings at 8 litres/dwelling/day, and one collector would be able to serve from 200 to 300 dwellings/day. At a density of 500 kg/cu. metre, the weight per load would be about 200 kg, excluding the cart, and this is well within the capacity of the average man to push, unless there are very steep hills, provided that wheels and bearings are of good design. The radius of operation of a handcart is only about one km, and thus frequent transfer points are needed. This question is discussed later under the heading of "Short-range transfer".

7.4 Animal carts

Until World War II, horses were widely used in Europe for door-to-door collection; horses, mules and bullocks are still used in many parts of the world. The capacity of draught animal carts ranges from two to four cubic metres and they often have tipping bodies, either by pivoting the body or by using a manually operated worm and nut. Animal carts have these advantages:

— no consumption of fossil fuels,
— very low cost compared with motor vehicles,
— almost silent in operation,
— the driver can leave the vehicle and assist in loading.

Their slow speed limits their effective radius of operation to about 3 km, and in busy streets they may interfere with motor traffic. This point is valid while they are travelling; during collection, however, a stationary motor vehicle is equally obstructive. Animal carts normally operate from a two-level transfer station at which they tip their loads directly into a large motor vehicle at lower level. Madras successfully operates this system and enjoys the advantages of both methods of transport: bullocks for the slow "stop-go" element and motor vehicles for high-speed transport over the relatively greater distance from the city to the disposal site.

There is a need to give much greater attention to the design of animal carts; they should be low-loading steel bodies mounted on pneumatic tyres, and fitted with sliding shutters and manually operated tipping gear.

7.5 Pedestrian-electric vehicles

These electric-powered vehicles, the driver of which walks in front, are employed in Britain for team-sweeping, but their capacity of two to three cubic metres gives them a potential for refuse collection as an alternative to animals. Since the speed is 5–6 kph., the radius of operation is only about 2 km. The battery can be charged overnight from a 13 amp outlet.

Its silent operation and lack of emission make it an ideal vehicle for night collection in narrow streets, but the capital cost is very high and restricts its adoption to the wealthier developing countries.

7.6 Motor-tricycles

The two-stroke, three-wheel motor-cycle is a much cheaper alternative to the electric vehicle. It can be fitted with a high-level tipping body of about two cubic metres capacity while retaining a low loading line. It is in common use in several cities in Asia and West Asia, particularly in old city centres where the streets are too narrow to admit larger vehicles. Its relatively high speed gives it an operating radius of about 10 km, but it does not operate well on the rough roads of a sanitary landfill. Thus, unless a refuse disposal plant is available, it should discharge at a transfer facility.

7.7 Tractors and trailers

One kind of motor vehicle which is almost universally available in developing countries is the agricultural tractor. It has a number of attractions:

- maintenance facilities are more readily available than for most other types of vehicle;
- together with a trailer, the capital cost may be only half that of a 5-ton truck;
- it is capable of hauling a large load relative to its h.p.;
- it is an ideal vehicle for operating on a sanitary landfill because of its large tyres and high torque;
- it has a power take-off from which hydraulic tipping gear on a trailer can be operated.

Despite its slow road speed of about 20 kph, it probably offers the cheapest method of motor transport for solid wastes up to a trailer capacity of about 6 m^3.

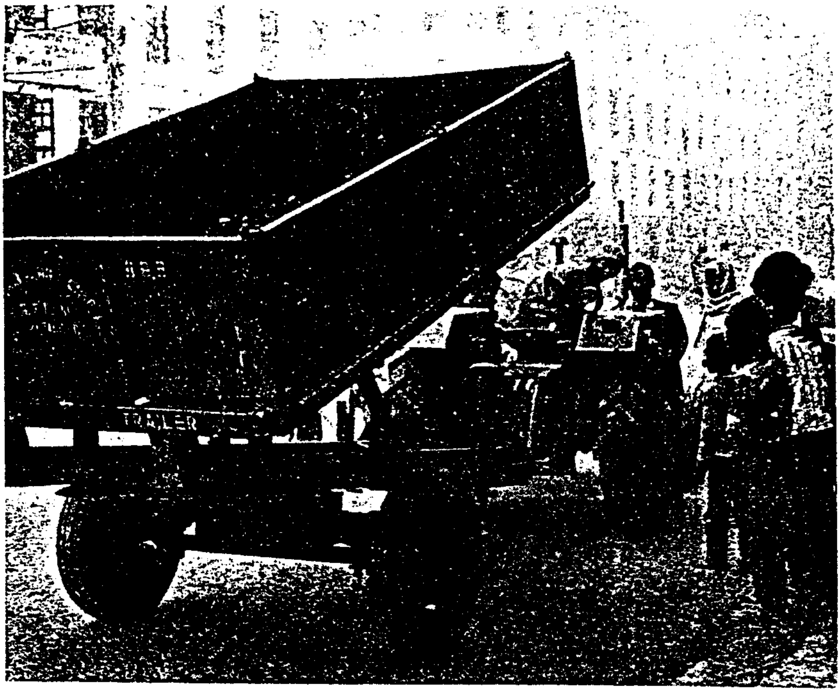
There are a number of variants of tractor-trailer systems. Mini-agricultural tractors or jeeps can be used with shuttered side-loading trailers up to 4 m^3.; agricultural tractors up to 6 m^3.; articulated semi-trailers are available with capacities up to 30 tons for long distance transfer.

The agricultural tractor and trailer is often used as a continuously coupled unit for the collection of refuse from houses or communal storage points, but it also has great potential as a transfer unit because of the ease with which the prime mover and the "body" can be separated.

The work performed by a refuse vehicle can be divided into two parts: the period while it is stationary during loading represents lost time for the prime mover; the other period which is spent travelling at normal road speed with a full load represents efficient use of the prime mover. Thus, for maximum productivity in terms of ton/km transported, loading time must be reduced to a minimum. If the vehicle can be split into the two parts, the prime mover and the body, loading time can even be eliminated by providing an extra body which can be loaded while the first one is being taken to disposal. If the tractor, the prime mover, can be used solely for the transport of full trailers loaded in its absence, it will be fully employed in travelling and in suitable conditions it is possible to transport double or treble the weight/day that could be achieved by a rigid vehicle. Those conditions can be:

- at large sources, such as markets, where a trailer can be stationed permanently and used as the communal container for the market,
- where the wastes from multiple small sources, such as dwellings, are collected by other means, such as handcarts, and brought to the trailer.

This method of using tractor trailer units will be further considered under short-range-transfer.



7. The simple tractor and trailer, used for secondary collection in Kathmandu, has hydraulic tipping gear. It was manufactured in India.

7.8 5–7 Ton truck

This is a type of vehicle available throughout the world and widely used for the collection of wastes from communal sites. It is designed primarily for the transport of building materials; the body, usually of steel, comprises a flat platform with hinged side and tail-boards 40–60 cm high. The volume is usually about 5–6 m^3, very suitable for high density materials such as bricks and aggregates. In its standard form this vehicle is rarely able to carry its rated payload of solid wastes; even high density wastes heaped on the vehicle would be unlikely to exceed four tons. It is a common practice, therefore, to extend the height of the sideboards in order to increase the cubic capacity. This makes it necessary to use ladders to load the vehicle, or to place men inside the body to receive baskets of wastes handed up to them by the collectors.

The commercial truck, however, has the following advantages:

— it is cheap, robust and easily obtainable,
— it has good ground clearance and performs well on rough ground.

There are four design features that enable these requirements to be met without complex mechanization of the body:

- reduction in the height of the chassis by the use of wheels of smaller than standard diameter*; this does, of course, reduce ground clearance;
- use of full forward control ("cab-over-engine") to increase space on the chassis for the body;
- extension of rear overhang;
- use of a long wheelbase.

By these means it is possible to provide an enclosed body of about 8 m^3 without exceeding the desired loading height of 1.6 metres. The most common type of body having these features is the side-loader. This has three or four loading apertures along each side and these can be closed by means of sliding shutters, usually plain sheets of metal running in grooves. The load can be trimmed within the body by the use of long-handled drags and during the final stages of loading can be heaped against closed shutters along one side. These vehicles should be fitted with hydraulic tipping gear.

7.10 Barrier loader

The barrier-loader has a van-type body, loaded from the rear. Hanging from roof-fixed rails is a movable barrier which extends across the body to a height of 1.6 metres above the floor. Loading begins with the barrier close to the front of the body and the collectors walk inside, using hinged steps at the rear, and deposit the refuse behind the barrier. When that space has been filled, the barrier is moved towards the rear of the vehicle. This is repeated in about six stages until the vehicle is full.

The contents are discharged by hydraulic tipping gear, the barrier swinging clear during this operation. Side loaders and barrier loaders were in common use in Britain from 1925 onwards, a period when domestic wastes had a density of 300 kg/cu.m or over, similar to that of many developing countries today.

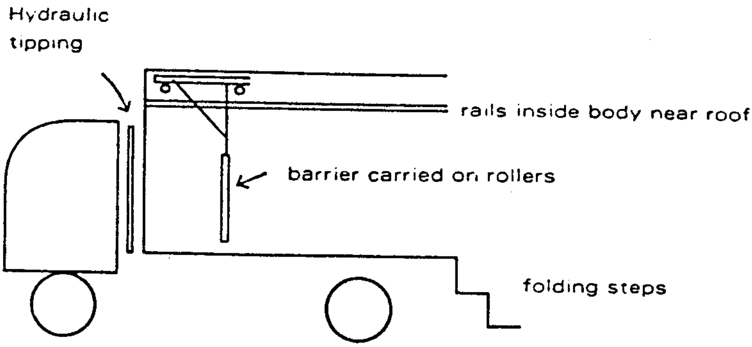
7.11 Fore and aft tipper

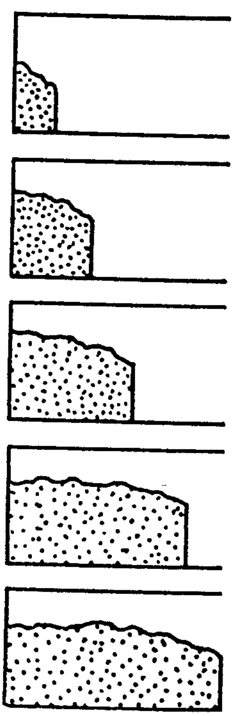
This is a design that appeared in the mid-1930s and was widely used in Britain until quite recently. Its main feature is that the body can be tipped two ways: towards the rear for unloading, and towards the front for the transfer of wastes loaded at the rear to the front end of the body. In a simple and rather clumsy way it achieves the same result as the hydraulic ram at the rear of a compactor vehicle, but the compression effect is much

* A reduction in the maximum permissible load results from the use of smaller than standard wheels and tyres. But the conventional 7-ton truck will rarely accommodate more than 6 m^3, weighing about $3^1/_2$ tons, and is normally under-loaded. A low-loading vehicle could be designed on the 7-ton chassis to have a body of about 8 m^3 for which a tyre rating of 5 tons payload would be adequate.

Figure 7(b)

BARRIER LOADER





STAGES IN FILLING VEHICLE

Collectors walk inside and empty bins over barrier. Barrier is moved manually towards the rear when available space has been filled

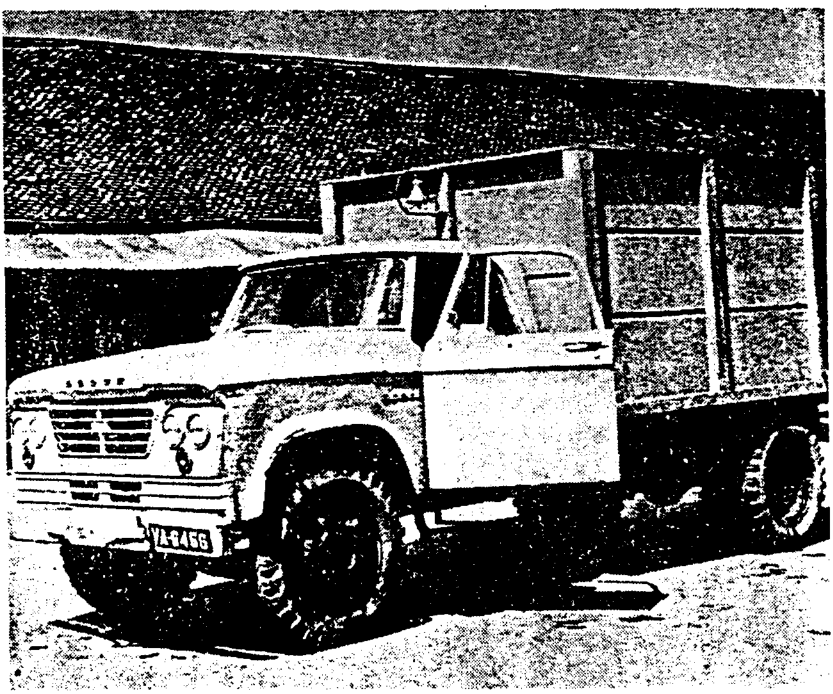
For high density wastes the barrier loader achieves a similar result to the compactor vehicle without employing costly hydraulic mechanisms, but it is more labour-intensive as the collectors have to walk inside the vehicle less positive. The forward tipping operation may be required about 12 times per load; a suspended barrier prevents the wastes from falling back after elevation of the body. Body capacities of about 12 m^3 were normal with this type of vehicle.

It represents a halfway stage towards compactor vehicles and is suitable for densities from 250 kg/m^3 upward. It can be built on a standard chassis with normal wheel diameter, and presents few maintenance problems.

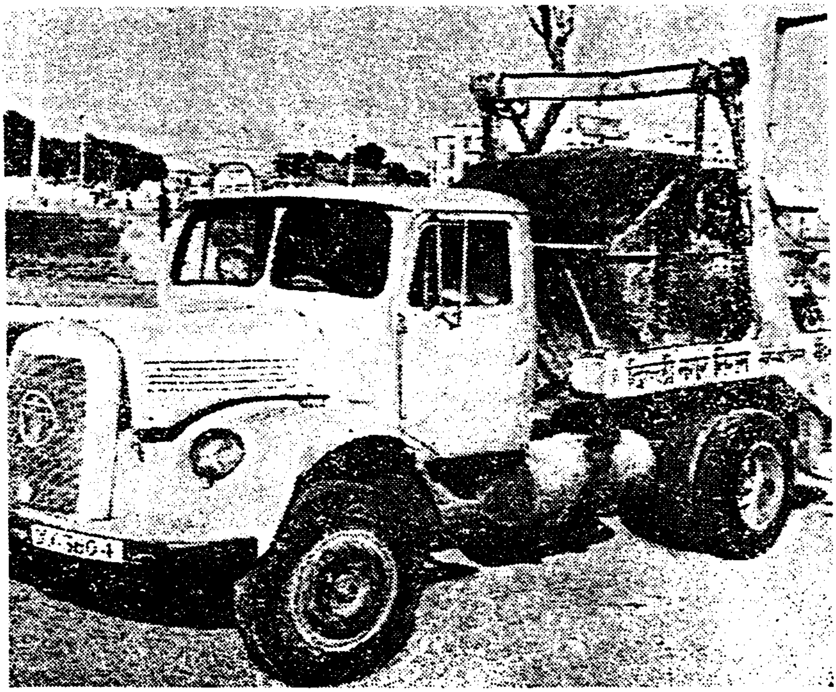
7.12 Container-hoist

This vehicle comprises a standard commercial chassis in the 5-10 ton range which is equipped with a pair of hydraulically operated lifting arms which are used to lift a detachable body on or off the flat floor of the vehicle. The detachable body is a metal box, called a "skip" in Britain, having a capacity from 3 m^3 upward. The skip can be tipped to discharge its load while in position on the parent vehicle.

The container-hoist is an alternative to tractor-trailer units and has the following advantages:



8. Standard commercial truck with extended sideboards to increase capacity. (Saigon)



10. Container-hoist vehicle, sometimes called a "dumper-placer" as used in Delhi.

7.13 Vehicle standardization

It has been observed that some developing countries have very mixed vehicle fleets and very low vehicle serviceability, down to 60% in some cases. These two things may be connected. If many different vehicle models are operated, it is virtually impossible to carry adequate stocks of spares; thus vehicles may be off the road for long periods while spares are purchased, sometimes through a centralized purchasing organization, which causes additional delay by requiring competitive tendering for even minor items.

Stores control can be simplified and spares availability improved by fleet standardization. Furthermore, major spare units (engines, transmissions, axles and hydraulics) can be held. These spare units are used to replace defective units in a vehicle which can then be put back on the road within a few hours and the units which have been removed can be repaired at leisure.

NOTE: Compactor vehicles have not been considered here for the following reasons:

(a) Compaction ratios achieved with western wastes of 100–150 kg/m^3 initial density range from 2:1 to 4:1, the final density in the vehicle

CHAPTER 8
ACCESS AND POINT OF COLLECTION

Thus far, the two main elements of a refuse collection service have been considered: storage of the wastes, and vehicles for collection. These elements are linked at the collection point, the location of which is conditioned by several factors:

— the physical characteristics of buildings;
— the access to the buildings and the width of roads;
— the proportion of the work of refuse collection which is carried out by the householder.

The storage system for solid wastes and the provision of access to the storage point for the refuse collectors should be given careful consideration at the design stage of any building. Town planning and building regulations in some countries deal with this matter and often require that plans for all new buildings be submitted to the department responsible for solid wastes services for its approval. But in most countries there has been little, if any, regulation of this kind, and every city contains numerous structures for which it is almost impossible to devise a satisfactory storage and collection method. This chapter reviews the main problems of access for refuse collection and it will be found that building construction and dwelling standards can be the main determinants of:

— frequency of collection,
— vehicle type and size,
— the duties which have to be imposed upon the householder.

8.1 Separate dwellings

The separate dwelling surrounded by a garden or a walled courtyard is ideal in most respects:

— the bin can be kept outside the house, in the open air,
— provided that the bin is impervious and has a lid, collection frequency is not critical: a twice-weekly collection would certainly be adequate;
— it is unnecessary (except for financial reasons, such as labour cost) to impose duties on the householder: the collector can enter the garden, carry out and empty the bin, and return it to its normal position.

When apartments have only one entrance it is possible to provide a door-to-door service. Collectors in Beirut were observed to carry large, strong, plastic sacks for apartment collections. The man went to the door of each apartment, knocked, and waited until the housewife brought out her kitchen bin. This he emptied into his plastic sack, which was large enough to contain the wastes from several apartments, thus reducing the number of occasions on which he had to leave the building to deliver wastes to the vehicle.

The alternatives are either batteries of small bins or a large container for communal use. In either case, the frequency of collection from apartment blocks should be daily because of limited storage space in the apartments and the likelihood that communal storage, if used, may be operated to a low standard.

8.5 One-room dwellings

In the poorer areas of many large cities a family may cook, eat and sleep in one room. This may be part of a much larger dwelling unit, or one of a large group of temporary or permanent shacks. In either case storage of wastes on the premises for more than a few hours is very difficult.

In the absence of any private space where a waste bin can be kept, public space must be made available. Thus in these conditions there seems no alternative to the provision of communal containers in the streets. These should be emptied daily.

Small communal containers closely spaced (not more than 100 m apart) are better than large ones at greater intervals because they are more likely to be used. Ideally, communal containers should be on a paved street wide enough for a motor vehicle, but small containers can be moved through narrow alleys on hand trolleys to the nearest road.

8.6 Markets

A common feature of most developing countries is the large market with stalls jammed closely together, fronting on narrow passages which are usually thronged with pedestrians and littered with wastes. Sweepers are usually employed to bring the wastes from the passages to a central storage point which is too often a large heap on the ground. This is removed from time to time by a motor vehicle and a collection crew.

At Doha (Qatar) a market was observed which provides a model system. Every stall has a steel bin of about 70 litres, and is visited by a sweeper with a trolley who exchanges full bins and empties them into a shuttered trailer of about 3 m^3 capacity stationed in a yard immediately adjacent to the market. When the trailer is full it is exchanged for an empty one by a Land-Rover.

8.7 Access for trailer or container exchange

There are usually several kinds of premises that produce wastes in quantities sufficiently great to justify the use of a trailer or a large container for central wastes storage. Typical buildings would be hospitals (for

11. An ideal method of storing market refuse. Every stall has its own bin which is emptied from time to time into a trailer in a yard. The trailer is towed by a Land-Rover (Doha)

domestic, not pathological wastes), barracks, very large hotels, large factories and office complexes, in addition to the markets already referred to.

The layout and the location of these storage points need careful planning, to enable the exchange to be effected with minimum effort and to avoid interfering with local traffic flow. The following are the main issues:

CHAPTER 9
BASIC COLLECTION SYSTEMS

Four basic collection systems have been evolved in relation to the amount of work imposed upon the householder:

— communal storage which may require delivery of the wastes by the householder over a considerable distance;
— block collection, where the householder delivers the wastes to the vehicle at the time of collection;
— kerbside collection, where the householder puts out and later retrieves the bin;
— door-to-door collection where the collector enters the premises and the householder is not involved in the collection process.

9.1 Collection from communal sites

The organization of refuse collection is greatly simplified by the use of large communal storage sites. The city of Delhi, for example, is served by about 1 250 sites having capacities from 0.5 to 10 tons for a population which exceeds 4 million. Delhi probably has about 800 000 separate sources of wastes (dwellings and shops) and a frequent collection direct from every source would require a much more complex organization and possibly greater expenditure. However, when sites are widely spaced, a great deal of domestic wastes are deposited in the streets by householders too lazy to carry it to the depot or masonry enclosure. It is significant, therefore, that only by employing about 10 000 sweepers is Delhi kept in a tolerable standard of cleanliness.

While the use of large communal sites may appear to be a fairly cheap and simple solution, it may transfer much of the burden of refuse collection on to the street cleansing service and actually increase total costs, because it is cheaper to collect refuse direct from a house than to sweep it up from the streets. In Delhi, in the year 1974 Rs 31 000 000 were spent on sweeping, and only Rs 7 330 000 on refuse collection.

The use of large, widely spaced communal storage sites is usually a failure because the demand placed on the householder goes beyond his willingness to co-operate. Communal storage points should, therefore, be at frequent intervals. Madras, Bangalore and Manila provide fixed

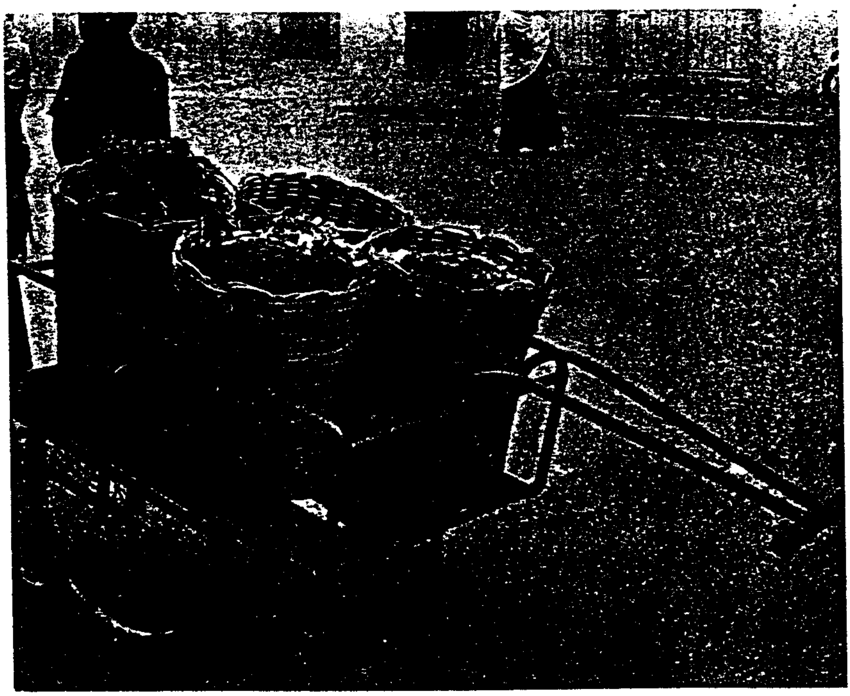
The daily performance achieved by this system is about 3.5 tons/man/day and 7.0 tons/vehicle/day.

9.3 Kerbside collection

This, like the block collection, requires a regular service and a fairly precise timetable. Residents must place their bins on the footway in advance of the collection time and remove them after they have been emptied. It is very important that bins of a standard type should be used, as otherwise it is likely that wastes will be put out in improvised containers, such as cardboard boxes, or even in loose heaps; when this occurs some of the wastes are inevitably scattered by animals and wind, thus increasing the work of street cleansing.

Kerbside collection is never entirely satisfactory. Problems include:

— bins sorted through by scavengers,
— bins stolen,



12. 4-Bin handcart made locally for a pilot test of house-to-house collection in Kathmandu. Baskets were chosen as containers to avoid importing galvanised steel bins. A design error was the use of bicycle wheels which broke up after a few months. Rickshaw wheels which have stronger spokes and rims would have been more satisfactory.

Collection method	*Frequency of coln.*	*Kg/pickup point*	*Crew no.*	*Tons/ man/day*	*Tons/ Veh/day*	*Dwellings/ man/day*	*Dwellings/ veh/day*
Communal:							
enclosures	daily	3 000	5	1.4	7.0	700	3 500
Concrete bins	daily	300	5	1.2	6.0	600	3 000
200-litre drums	daily	50	2	5.0	10.0	2 500	5 000
Block	2 days	4**	2	3.5	7.0	850	1 700
Kerbside	daily	2	4	0.6	2.4	300	1 200
	4 days	7	4	1.8	7.0	250	1 000
	weekly	14	4	2.8	11.0	200	800
Door-to-door	daily	2	6	0.3	2.0	160	960
	4 days	7	6	1.0	6.0	140	850
	weekly	14	6	1.7	10.0	120	720

The four most productive methods are as follows:

	Tons/per man/day	*Tons/per vehicle/day*
Communal 200-litre drums, daily	5.0	10.0
Block collection every 2 days	3.5	7.0
Kerbside collection every 4 days	1.8	7.0
Communal masonry enclosures, daily	1.4	7.0

Figures for weekly collection have not been included, having little practical significance for most developing countries.

** per house

The broad conclusions that can be reached are as follows:

Communal storage systems based on manually portable containers probably offer the lowest collection cost.
Block collection at two-day intervals appears to offer a low collection cost and avoids all the problems that arise with communal storage or kerbside collection.
Door-to-door collection by a heavy motor vehicle and crew would be by far the most expensive system for a developing country if a daily service is required. It may be at an acceptable cost level in selected areas if a twice weekly service is adopted.

The conventional western approach may have to be ruled out. There are other effective possibilities. One of these is described in the next chapter.

A typical performance calculation for handcart collection would be as follows:
Assume that the handcart carries six bins of 50 litres capacity, the small size being dictated by high density wastes. When full, the handcarts would be pushed to trailers of 6 m^3 capacity, spaced about one km apart. Thus the collectors operating from each trailer would be within a radius of about 700 metres and their average distance from the trailer would be about 400 metres.

Handcart capacity, 6 bins × 50 litres	300 litres
Therefore, one handcart load @ density 330 kg/m^3 =	100 kg
If generation of wastes is 2 kg/dwelling/day, one handcart load is equivalent to	50 dwellings
Time per load:	
collection, 1.5 minutes/dwelling	75 min
travel, 400 metres × 2 @ 3 kph	16 "
unload	5 "
delay allowance	10 "
Total time/load	106 minutes
Working time/shift 420 minutes	= 4 loads/shift
Production per shift	200 dwellings or 400 kg

10.1.2 Secondary collection by tractor-trailer Assume that trailers have a capacity of 6 m^3 and that they are exchanged when full by an agricultural tractor which takes them to the disposal site.
Assume an average round trip to the disposal site of 12 km at an average speed of 15 kph

Time travelling per trip	48 minutes
Exchanging trailers	5 "
Unloading	10 "
Total trip time	63 "

If 7 minutes/trip is allowed for delay, then average trip time would be 70 minutes, equivalent to 6 trips/day in a working day of 7 hours.
If the average trailer load is 2.4 tons (equivalent to a loaded density of 400 kg/m^3), then the tractor production/shift is equal to 14 tons.

The number of trailers required depends primarily upon population density. One trailer exchanged 6 times/day could support 36 collectors serving a population of 43 000, but because of the limited operating range of a handcart, this 36–man unit must be contained within an area of one square kilometre. Thus, in this example, if the population density is less than 43 000/km^2, more than one trailer transfer point will be required. Two transfer points, each having a trailer exchanged 3 times/day, would enable the tractor and 36 collectors to cover an area of 2 km^2 with a population density of 21 500/km^2.

In the first instance the theoretical trailer requirement would be two per tractor, one stationary at the transfer point, the other being towed. In the second the number would be three per tractor, one at each of the two transfer points and one being towed. In practice it is usually necessary to provide surge capacity at a transfer point, because the rates of handcart collection and trailer exchange are not continuously in balance. Trailer numbers should, therefore, be on the following scale:

Optimum population density	3 trailers/tractor, 2 at transfer.
Half optimum population density	5 trailers/tractor, 2 at each transfer point.

The minimum population density for which handcarts could be used is 7 200/km^2, when each sq.km would require six collectors and one trailer/transfer point. Surge capacity would not be necessary, and thus the ratio of trailers to tractors would be 7:1, 6 trailers at transfer points and one being towed.

All these figures are based on the assumed basic data given at the beginning of this chapter; for any specific city corrections must be made in accordance with local data. In general, the use of short-range transfer based on handcarts is relevant to the following conditions:

— low per-capita generation of wastes,
— high density wastes,
— high population density,
— low wage rates.

Where one or more of these conditions are absent, the principle of transfer may still be valid, but it may be necessary to employ larger vehicles.

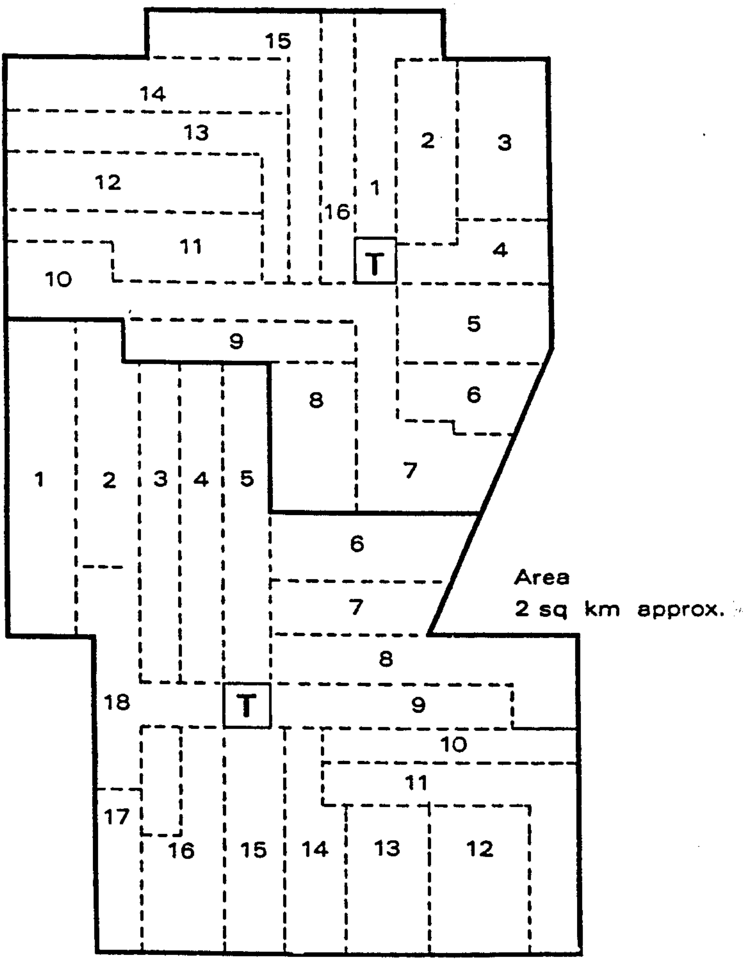
10.1.3 Primary collection by animal cart or motor-tricycle The following assumptions are made:

Vehicle capacity (one vehicle load)	2 000 litres or 700 kg 350 dwellings
Time per load:	
2 crew × 40 dwellings/man/hour	4 hours 22 minutes
Travel 2 km:	
Animal cart (3 kph)	40 minutes
Motor tricycle (20 kph)	6 minutes
	Unload 10 minutes
Total time/load:	
Animal cart	5 hours 12 minutes
Motor-tricycle	4 hours 38 minutes
Loads/day:	
Animal cart, 1$^1/_4$ loads	total weight/day 875 kg
Motor-tricycle, 1$^1/_2$ loads	total weight/day 1 050 kg
Production/man-shift:	
Animal cart, 2 crew	437 kg, 219 dwellings
Motor-tricycle crew	525 kg, 262 dwellings

10.1.4 Secondary collection from transfer station The main advantage conferred by animal carts or small motor vehicles is a wider range of operation. The animal is just as slow as a handcart, but the volume of the

Figure 10

TYPICAL ROUTE LAYOUT FOR SHORT-RANGE TRANSFER DISTRICT



Population 43,000. Dwellings 7,200. Total 14 tons/day.

1 Tractor, 2 Transfer points each having 2 trailers
(3 exchanges/day at each).
36 collectors each with handcart. Each transfer point serves 18 collectors.
Collection routes are arranged, as far as possible, radial to transfer points, shown as T.

When handcarts are used for primary collection—or motor-tricycles the bodies of which can be tipped at a discharge height of a metre or more—static packers can be used at level sites. They are considered later in this chapter.

10.2.2 Split-level sites Whenever the direct discharge from the body of one vehicle into another is necessary, a two-level site must be created unless plant is installed in the form of a below-ground hopper which feeds an elevating conveyor.

The traditional form of a split-level transfer station is a loading quay (about 3 metres above ground level) which is reached by an inclined road having a gradient suitable for the smaller vehicles: 1:12 is usually acceptable and this requires an approach road about 40 metres long. If one-way traffic movement is desired, two ramp roads must be provided.

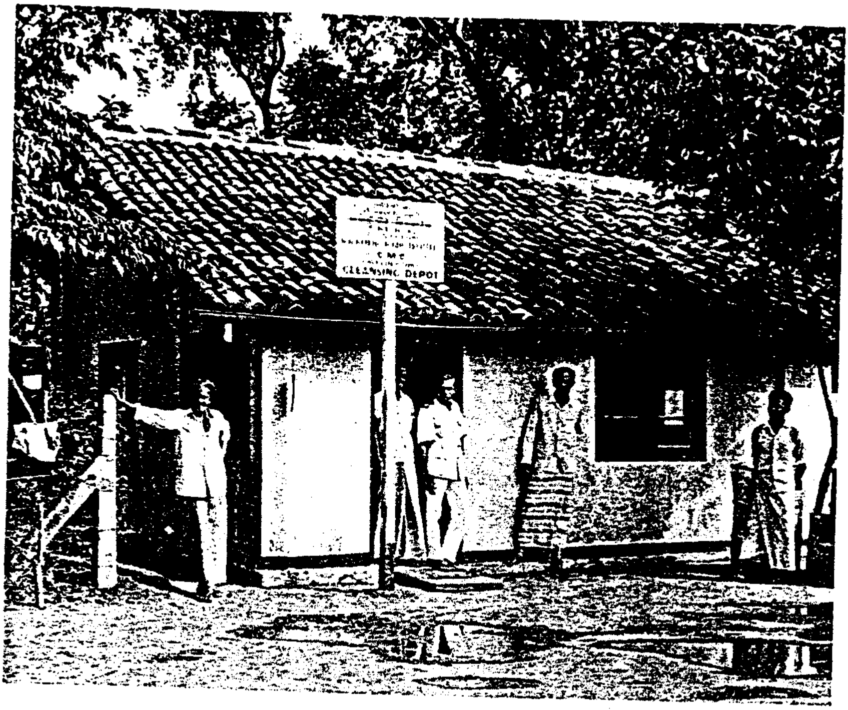
10.2.3 Static packers Large static packers are widely used in the industrialized countries at long-range transfer stations designed to receive loads from compactor vehicles of about 5 tons for transfer to vehicles carrying up to 18 tons, for transport to disposal sites which may be as far away as 80 km. In order to achieve loads of this weight the wastes must be compressed and the system employed is to discharge the incoming wastes into hopper at lower level from which they are fed into the receiving vehicle by a hydraulically operated pressure plate. These are usually two-level sites.

Small static packers which operate on a level site are commonly used at factories to fill containers of 8 m^3 upward with low density industrial wastes, and these can readily be adapted to short-range transfer stations when their cost can be justified. This is most likely to be in the wealthier developing countries where packaging materials form a significant element of domestic wastes so that the densities of these wastes often approximate to those of Europe or USA. Static packers have been proposed for a series of transfer stations, which will be served partly by handcarts and partly by small motor vehicles, in a system devised by consultants for Riyadh, Saudi Arabia.

The potential throughput of a static packer is very high. One serving a container of 15 m^3 volume, and achieving a compaction ratio of 2:1, where the containers are exchanged five times/day, has a theoretical throughput of 150 m^3/day, equivalent to 30 tons at a density of 200 kg/m^3. Such high capacity can be extremely valuable in a densely populated area, or one where there is a very high production of wastes from markets, by reducing the number of transfer stations required, because it is in just such areas that sites for transfer stations are most difficult to find.

10.2.4 Combined transfer stations and district depots Where a transfer station serves a population in the range 20 000 to 50 000, there are many advantages in building a combined transfer station and depot.

For a population in this range there would probably be between 40 and 150 manual workers employed on refuse collection, street cleansing, and



13. A small district depot in Colombo which provides a parking area for handcarts and a transfer facility for sweepings in a yard at the rear of the building.

ancillary services. This represents a work unit of convenient size for the most junior level of qualified management, the district inspector.

A district depot should provide the following facilities:

— welfare facilities for workers: lockers, toilets, showers,
— small stores: brooms, shovels, cleaning materials, lubricants, etc.,
— parking facilities for hand trucks for sweepers, and, if appropriate, refuse collectors.
— office and telephone for the district inspector.

A good basic design for a combined district/transfer station would be:

Ground floor	transfer and parking facilities.
First floor	office and stores.
Second floor	locker room, toilets, showers.

CHAPTER 11
ECONOMICS OF REFUSE COLLECTION

11.1 Crew collection

Crews numbering two to eight are used for collection from communal storage sites, for kerbside and for door-to-door collection. In this chapter the factors that determine optimum crew size are considered.

In the case of collection from masonry enclosures each containing from half a ton to five tons of wastes at ground level, which are transferred to the vehicles by rakes and baskets, the limit on crew size is imposed only by the number of men who can simultaneously empty a basket into the vehicle. Within that limit every additional increment of labour adds an equal amount of productivity. It is customary to employ about 6 men in these teams, but situations have often been observed in which up to 12 men could be effectively employed with one vehicle: 4 men filling baskets and 8 men carrying baskets to and from the vehicle. But such sites are usually several hundred metres apart, and it is necessary to transport the collectors between sites; in practice, therefore, space on the vehicle for transport of the crew could be the main constraint on crew size.

Where cylindrical concrete bins are fixed to the footway the number of men who can work simultaneously transferring wastes from the bins to baskets is limited by the small diameter of the bin. Usually only one or two men can work at the same time, and therefore the largest number that can be effectively employed lies between three and six, according to the relative work content of basket filling and basket carrying.

If 200-litre drums are placed at intervals on the footway or verge, singly, the maximum useful crew size is two men, unless the vehicle is an open one of excessive height, in which case one or two men may be required in the body of the vehicle, to assist with emptying.

In the case of block collection it is never necessary to employ more than two men as their only task is to stand at the rear of the vehicle and empty bins handed to them by residents.

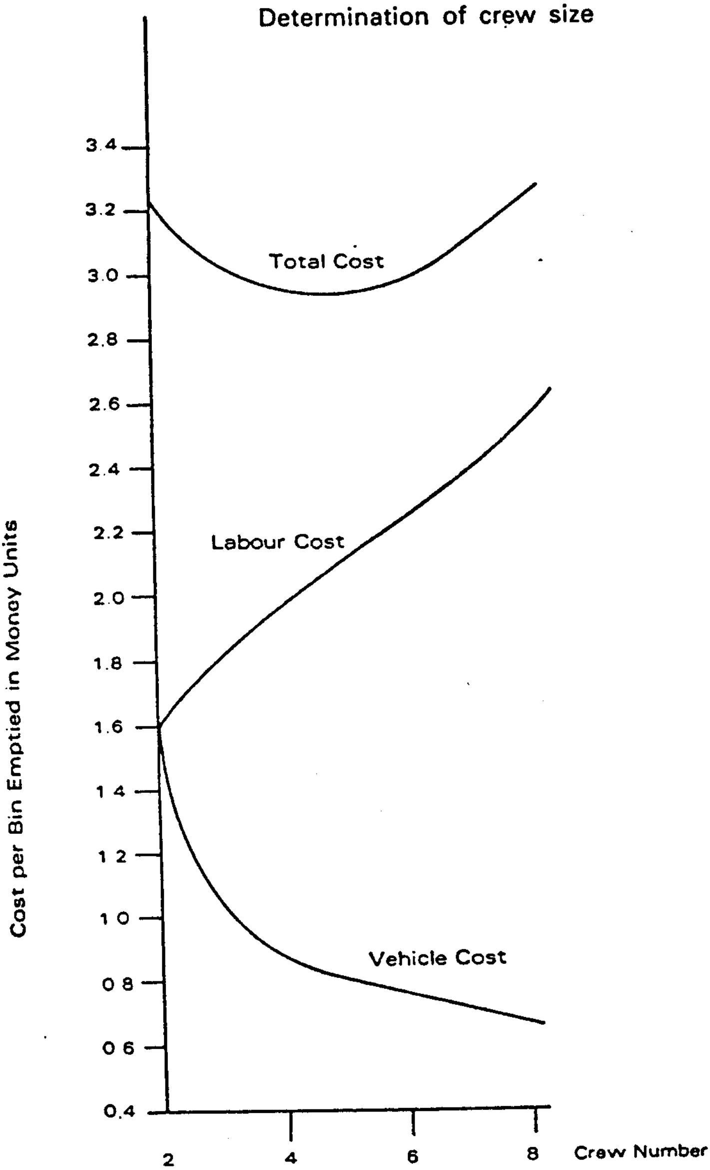
In all these cases there is an obvious crew size dictated by the nature of the task or there is a constraint on crew size imposed by an external factor, such as transport facilities for the crew.

11.1.1 Door-to-door and kerbside collection For these two systems the choice of the most economical crew size is more complex. For door-to-door

Figure 12

CREW COLLECTION, DOOR-TO-DOOR

Determination of crew size



For a high ratio of wage rate to vehicle cost, 1:2, a small team achieves the lowest cost.

crew should be accompanied by a supervisor who will record the total number of bins emptied and the elapsed time between the starting and finishing points. For single-side working, crews of 1, 2, 3, and 4 should be used on successive occasions, and for double-side working crews of 2, 4, 6 and 8. Each test is repeated at least four times, varying the members of the crew to balance out personal characteristics.

The result of a test of this kind which was carried out by the writer in an area of detached houses, standing in gardens, and receiving a full door-to-door service, was as follows:

Crew number	Bins/man/hour	Bins/crew/hour
2	30	60
4	25	100
6	22	132
8	19	152

This clearly shows the decline in labour productivity which occurs with each additional labour increment; that decline is, however, accompanied by rising vehicle productivity which is proportionate to the number of bins emptied/team/hour. (It should be noted that for all crew sizes the labour productivity in this example is very low, because the area selected for test represents the worst conditions: long frontages, and long walks within private gardens).

To determine optimum crew size from this kind of test it is next necessary to apply unit cost for labour and the vehicle. To demonstrate this, an imaginary currency called "money units" has been used, and the performances above have been applied to two tables in order to illustrate the importance of labour: vehicle cost ratios.

The first table is for low wage rates; the hourly wage is 10 money units; the hourly vehicle cost is 100 money units.This would be fairly typical for much of Asia. The second table is for high wage rates; the hourly wage is 50 money units, and the vehicle cost is again 100 money units/hour.

Crew no.	Bins man/hr	Labour cost per bin	Bins/vehicle hour	Vehicle cost per bin	Total cost per bin
Low wage rate: 1 man/hour = 10% of 1 vehicle/hour					
2	30	0.33	60	1.60	1.93
4	25	0.40	100	1.00	1.40
6	22	0.45	132	0.75	1.20
8	19	0.53	152	0.66	1.19
High wage rate: 1 man/hour = 50% of 1 vehicle hour					
2	30	1.66	60	1.60	3.26
4	25	2.00	100	1.00	3.00
6	22	2.27	132	0.75	3.02
8	19	2.63	152	0.66	3.29

(2) *Deterministic*: In this method a model is developed and by using a digital computer an optimum solution can be obtained.

Models for use in developed countries having 'house-to-house' collection systems are available. However, in the majority of developing countries the 'community bin system' is commonly used and hence these models cannot be directly applied. Modification of these models to suit 'community bin systems' is needed.

(3) *Heuristic - Deterministic*: In this method, a number of possible alternatives are first identified and then, for the existing constraints, the most possible solution is identified.

11.2 Vehicle operating costs

The following cost estimates (1975 price level) are derived from actual operating cost supplied by several Indian cities and updated where necessary. The fuel costs used are: diesel Rs 1.16/ litre, petrol, Rs 3.50.

5–ton diesel truck, 6 m^3, 60 km/day

		Rs annual
Capital cost Rs 140 000, 10-year life:		
Depreciation, annual	Rs 14 000	
Interest 10% reducing loan	7 000	
Amortization		21 000
Fuel and lubrication		9 500
Repairs and maintenance		14 000
Tyres, etc		4 000
Wages		5 300
TOTAL ANNUAL COST		53 800
DAILY COST 310 days/year*		174

10-ton diesel truck, 10 m^3, 150 km/day (used for secondary collection from a transfer station)

Capital cost Rs 160 00, 10-year life:		
Depreciation, annual	Rs 16 000	
Interest, 10% reducing loan	8 000	
Amortization		24 000
Fuel and lubrication		20 000
Repairs and maintenance		20 000
Tyres, etc		7 000
Wages		6 000
TOTAL ANNUAL COST		77 000
DAILY COST, 310 days/year (Equivalent to Rs 10/ton for 5 loads/day × 5 ton)		248

* NEERI suggest that 300 days/year is more commonly used in India for costing purposes.

operating costs of the preceding section, and the performances that appear in Chapter 9.5.

Communal Storage, Daily	
Masonry bins	
7 tons/day	*Cost/ton Rs*
5-ton motor truck, Rs 174/day	25
Crew, 5	7
TOTAL	32
200-litre drums	
10 tons/day	
5-ton motor truck, Rs 174/day	18
Crew, 2	2
TOTAL	20

House-to-House Collection, Twice Weekly (Practicable only for dwellings with yards or gardens)	
Motor truck, 8 crew	
(20 dwellings/man/hour × 8 men × 5 hours × 8 kg, say 6 tons/day)	
5-ton motor truck, Rs 174/day	29
Crew, 8	12
TOTAL	41
2 Bullock carts in relay	
(20 dwellings/man/hour × 4 men × 6 hours × 8 kg, say 4 ton/day)	
2 bullock carts, × Rs 45 = Rs 90/day	22
Crew, 4	10
If within 3 km of disposal site, Total	32
If outside 3 km radius of disposal site, add:	
Transfer cost	4
Secondary collection, 10-ton trucks	10
TOTAL	46

House-to-House Collection, Daily	
Handcarts	
Handcart	3
Collection, 0.4 ton/man/day	25
Transfer	4
Secondary collection by tractor-trailers	14
TOTAL	46
Single bullock cart	
(25 dwellings/man/hour × 6 men × 6 hours × 2 kg, say 1.8 ton/day)	
Bullock cart, Rs 45/day	25
Crew, 6	33
Transfer	4
Secondary collection by 10-ton truck	10
TOTAL	72
Motor truck	
(25 dwellings/man/hour × 8 men × 6 hours × 2 kg, say 2.4 ton/day)	
5-ton motor truck, Rs 174/day	73
Crew, 8	33
TOTAL	106

CHAPTER 12
STREET CLEANSING

The sweeping of streets is such a simple and humble occupation that it rarely attracts technical interest. However, many cities spend between a third and a half of their solid wastes budgets on street cleansing. It is a service for which a wide variety of tools, equipment and methods, both manual and mechanical, are available, and it is one in which there is often great scope for financial saving by the introduction of more efficient methods.

This is an area in which public relations are very important. Much of the work arises directly from shortcomings in public behaviour, such as throwing litter in the street. In some cities, however, a high proportion of street wastes arises from deficiencies in the refuse collection service as a result of which residents dispose of domestic and shop wastes in the streets.The cost of removing wastes which have been scattered in the streets is very much higher than the cost of collecting similar wastes which have been placed in containers such as domestic wastes bins or litter containers.

Thus street cleansing policies should have the following objectives:

- — the provision of services for the collection of wastes from source, i.e., efficient refuse collection,
- — reduction of street litter by public education,
- — the use of systems which achieve high labour productivity,
- — the design and use of effective tools and equipment.

12.1 Sources

For purposes of solid wastes management all street wastes fall into three main categories:

12.1.1 Natural wastes These include dust blown from unpaved areas, sometimes from within the city and sometimes from a great distance, and decaying vegetation such as fallen leaves, blossoms and seeds which originate from trees and plants in the city. Natural wastes cannot be avoided, but may be controlled by such measures as the careful selection of the types of tree planted in the city.

long and flexible, is swept across the body in long strokes and the fibres exert very little pressure on the ground, a fact that makes it an excellent tool for sweeping litter and leaves from unpaved surfaces where minimum ground friction is desirable. The stock broom is pushed ahead of the sweeper with frequent short strokes to which much of the weight of the body can be applied. Thus, having shorter and stiffer filaments, it is more effective in dislodging adhering matter and in collecting dust, partly because of the probing action of the springy filaments and partly because of the sweeper's weight applied to it.

Bunch brooms are in general use in tropical and sub-tropical countries because they are very cheap to manufacture and use local fibres. They cover the ground fast, but do not remove heavy fine wastes effectively.

For channel sweeping, stock brooms of about 30 cm filled with a natural fibre (Bahia or Calabar bass) have been widely used in Europe, but in recent years man-made fibres such as polypropylene have tended to replace natural fibres as they have a longer life. Split cane would be satisfactory and economical in many countries.

For the sweeping of footways and other large paved areas, stock brooms of 40 to 50 cm, filled with soft fibres, are successful in removing both litter and fine dust.

Thus the normal equipment of a sweeper should be a channel broom and a pavement broom. If unpaved areas are included in his beat, he will also require a long-fibre bunch broom for this part of his work.

(b) *Shovels.* The function of the broom is to gather the street wastes into small heaps which then have to be picked up completely and placed in a receptacle. The conventional tool for this purpose is a large straight-blade shovel. However, when the wastes comprise large quantities of very light materials such as leaves, a shovel is ineffective because dried leaves fall of or are blown away during transfer. A good solution to this problem is to use a pair of flat boards, usually plywood, between which the wastes are retained by hand-pressure.

(c) *Handcarts.* See section 12.2.3

12.2.2 Sweeping methods In the normal sweeping situation of footway and channel there is an established work method for a single operator which has been designed to minimize unproductive walking:

1. Park receptacle (normally a handcart) at commencement of section to be swept.
2. Using wide broom, sweep wastes off footway into channel for a convenient distance, say 20-50 metres.
3. Sweep channel in reverse direction, ending at parked receptacle; make intermediate heaps if quantity so requires; *do not sweep across drainage grids.*
4. Move receptacle up to next section to be swept, picking up heaps on the way.

When sweepers are employed in teams of three to five men, a much larger vehicle capacity is necessary. This can be provided in the form of a horse-drawn cart or a bullock-cart, or a small motor vehicle. It is important that the vehicle following a sweeping team should be in close attendance; heaps of sweepings that have been left for several minutes are likely to have been scattered by the wind or by traffic.

12.2.4 Classification of streets For the effective planning of manual sweeping it is necessary to classify streets, or sections of streets, according to the required frequency of sweeping. The following is a typical method of classification:

Class	*Character of street*	*Frequency of sweeping*
A	City centre shopping	5 x daily
B	Market areas	5 x daily
C	City centre main streets	2 x daily
	Suburban shopping streets	2 x daily
D	City centre minor streets	1 x daily
	Suburban main streets	1 x daily
E	Residential streets, low income	3 x weekly
F	Residential, high income	1 x weekly

Each city should determine its own frequency requirements and develop an appropriate classification system. Time studies should then be carried out for each class of street and the results of these will indicate the length of street that a man can sweep at the required frequency. For example, time studies may show that for Class A streets one man can be allocated between 250 and 300 metres, while for Class F the length may be as great as 10 km.In measuring work content, sub-classification may be necessary to take account of variation in wastes generation within a given class.

On the basis of this information a city can be divided into sweepers' beats which contain fairly uniform workloads, despite great differences in the lengths to be covered.

12.2.5 Organization of manual sweepers For the effective management of sweepers, and for the transfer of their collected wastes, depots are required with the following facilities:

- — office for the district supervisor, where sweepers book on and off,
- — parking area for handcarts,
- — tool and equipment store,
- — transfer facility for sweepings,
- — toilet and welfare facilities.

Each depot should be located, as far as possible, at the centre of a sweeping district, the area of which will be determined by the number of sweepers and the lengths of their beats. In a city centre beats will be short and there may be more than 40 sweepers employed per square km; thus depots may be required on a grid of 1 km. In this case the average walking distance from beat to depot would be less than 500 metres. In a suburban

Litter bins should comprise an outer casing of standard colour and lettering, and an inner container which is easily removed by authorized persons for emptying. Size should relate to spacing and frequency of emptying, but the normal maximum should be about 100 litres which represents the upper limit for one man to lift and empty, even when the wastes are of low density. Large litter bins must be pavement mounted; this can be expensive and they also form obstructions. The smaller sizes, from 30 to 50 litres, can be mounted on street lighting columns by means of steel bands and many cities have found this a good and cheap system. The top aperture of a litter bin should be partly shielded to minimize loss of contents in high winds.

12.3.2 Siting and emptying The siting of litter bins could be based on the streets classification referred to in 12.2.4. For example: Class A, 1 bin to each lighting column; Class B, one to every second column; Class C, one to every fourth column. If the bins were emptied by a sweeper every time he passed, the frequency would be Class A, 5 times daily; Class B, twice daily; Class C, once daily.

It is rarely possible for the larger sizes of litter container to be emptied by a sweeper owing to the limited capacity of a handcart. Such bins could be included on the routes of the refuse collection service unless more frequent emptying was needed, in which case special vehicles would have to be employed.

12.4 Mechanical sweeping

Most mechanical sweepers are suction machines, usually assisted by one or more revolving "scarifying" brushes for dislodging adhering matter. They range in size from small pedestrain-controlled pavement sweepers to large channel sweepers which often have an auxiliary engine to provide suction. The smallest machines operate at about 3 kph, the largest at 8 kph or faster. Some of the latter can be fitted with a wander-hose which can be controlled by an attendant and used to pick up refuse from inaccessible places; for example dry leaves from a drainage ditch.

Pavement sweepers are not usually practicable for cleaning normal footways because of obstructions such as lamp-columns, and the presence of pedestrians. Their main application is for very large paved areas such as central reservations and car parks. When they can be deployed effectively, they are very efficient for the removal of fine dust.

Channel sweepers have the same virtue, but they also have serious limitations, in particular:

- no car parking can be allowed on mechanical sweeper routes,
- well-engineered roads are essential, particularly channel and kerb alignment,
- the serviceability of mechanical sweepers is low compared with most other vehicles,
- they are subject to damage by heavy objects lying on the road, or during travel over rough ground at disposal sites.

CHAPTER 13
TREATMENT AND DISPOSAL

Over 90% of the world's solid wastes are disposed of in landfills. Sanitary landfilling is the main method used in the West: crude dumping is very common in the developing countries.

There is no form of treatment that can entirely avoid the need for land for final deposit. Treatment often enables a proportion of the wastes to be utilized in some way, but there are residues from all forms of treatment and the need for land space is rarely reduced by more than 70% (See Figure 16). Thus sanitary landfilling is usually necessary, although on a reduced scale, whatever form of treatment may be adopted. The most common forms of treatment are:

— size-reduction of the wastes by shredding or pulverization, in order to improve the land-filling qualities of the wastes, or as a stage in a composting process;
— composting, a system for controlling the natural decomposition process to produce an organic fertilizer:
— incineration, the primary purpose of which is to render the wastes inert, but which also reduces volume, and may sometimes provide a source of energy.

All these forms of treatment provide opportunities for recycling, because facilities for the extraction of saleable materials can be incorporated in the plants.

13.1 Recycling

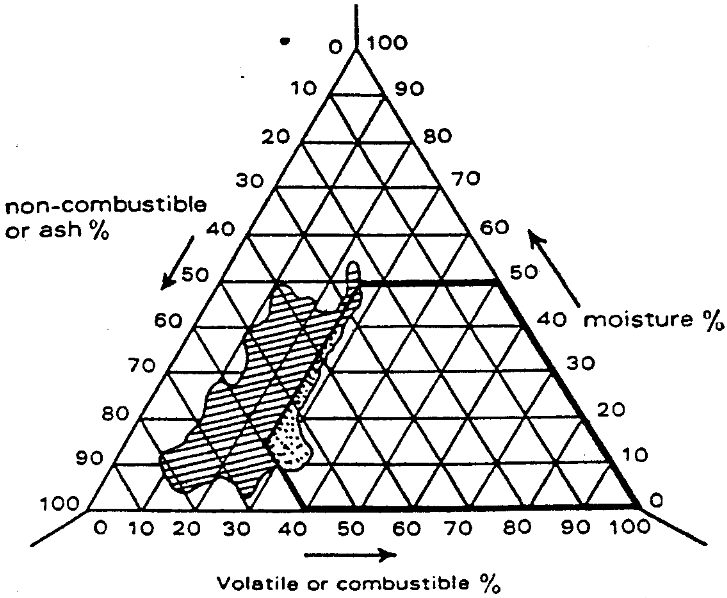
The constituents which are commonly extracted from domestic-trade wastes for industrial use are:

— paper, for re-pulping;
— textiles for paper-making, machinery wipers, etc.;
— metals for re-melting;
— glass for re-melting or abrasives manufacture, etc.;
— rubber for a downgraded use;
— plastics for the production of an inferior grade.

Figure 15

THREE COMPONENT DIAGRAM ILLUSTRATING THE UNSUITABILITY OF INDIAN WASTES FOR INCINERATION

(Adapted from "Solid Wastes Management in India", W.H.O., SEA/Env San/167, 1976; p. 34, Mr. A.D. Bhide, NEERI.)



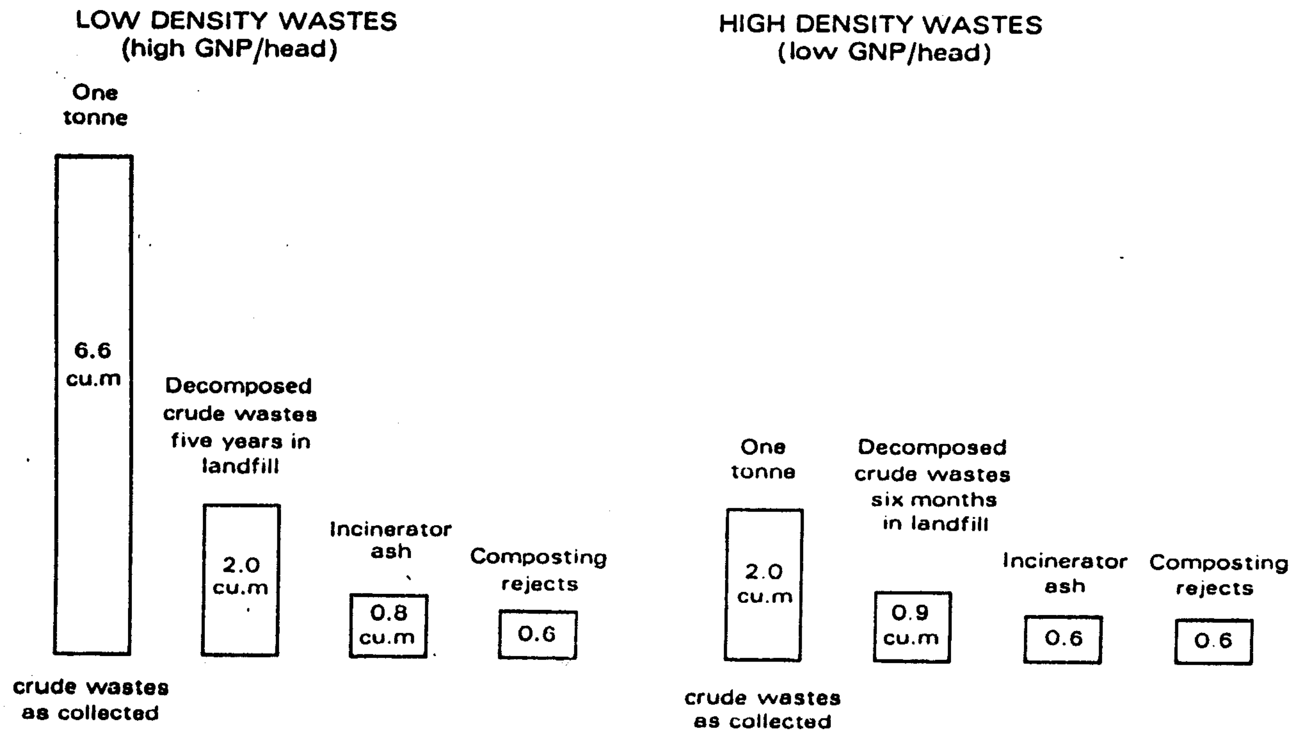
Zone in which self-sustaining combustion reaction can be obtained

Zone in which values from 33 Indian cities lie

Zone in which values from some Indian cities lie giving self-sustaining combustion reaction

Figure 16

PROBABLE LAND SPACE REQUIRED FOR SANITARY LANDFILLING OF UNTREATED WASTES COMPARED WITH SPACE REQUIRED FOR RESIDUES OF TREATMENT



Composting:		
minimum mechanization	5 " minus income,	say 2 net
full mechanization	10 " " "	say 7 net

At the time of writing, the cost unit for much of Asia could be taken to be about Rs 10. This assumption makes it possible to measure the cost impact of a disposal method in the following way.

At a low rate of wastes generation, 400 g/person/day, the weight to be disposed of/person/year would be 150 kg. The comparative costs per person/year, at 1975 price level, are, therefore:

Sanitary landfill	Rs 1.5
Manual composting	3.0
Incineration	22.5

13.6 Environmental aspects

(a) *Landfill.* Every crude dump is an environmental disaster causing health risks from flies and rats, air pollution from deliberate or accidental burning and water pollution through leaching by rainfall.

At a sanitary landfill vectors are controlled by the operating method. Groundwater pollution is avoided by careful site selection and surface water pollution is avoided by preliminary site engineering. Thus a well-managed site involves no risks of pollution transfer to water or atmosphere. Some short-term environmental degradation may be unavoidable in the form of traffic to and from the site, a scarred landscape caused by earthmoving operations, some visible refuse at most times, wind-borne litter during gales, and the noise of tractors.

If a sanitary landfill site provides restoration of a former surface mineral excavation, or improves a natural feature by creating a park on estuarial mud, then it confers long-term environmental benefits which heavily outweigh the short-term problems.

(b) *Composting.* Composting systems, both manual and mechanized, can be designed and operated so as to provide effective control over disease vectors, but it is rarely possible entirely to avoid occasional offensive odours. The solution to this lies in careful site selection. The possible economic importance of composting to certain developing countries has already been stressed. There may also be significant advantages to public health because it is often the custom for farmers to collect crude wastes and to use them as fertilizers without any proper treatment or control, thus causing risks which would be avoided if the wastes were processed into a hygienic product by the local authority.

(c) *Incineration.* Incineration has no obvious environmental advantages; in fact, it sometimes presents environmental problems. A very tall chimney is necessary to ensure that the effluent gases do not descend over the surrounding area; water consumption for gas cooling and clinker quenching may be very high; particle emission can seldom be controlled to

CHAPTER 14
SANITARY LANDFILL

14.1 Introduction

Sanitary landfill can be defined very simply as the use of solid wastes for land-reclamation, a typical example being the restoration, by filling to the original level, of man-made surface dereliction such as a disused surface mineral excavation. Solid wastes may also be used to improve natural features by raising the level of low-lying land to enable it to be used for cultivation or industrial development. Described in this way, sanitary landfilling has the virtue of being a method of refuse disposal which confers environmental improvement by restoring dereliction or improving natural contours.

Most solid wastes, however, are very offensive materials which provide an attractive habitat for such disease vectors as flies and rodents, and which pass through a lengthy process of decomposition the products of which can cause serious water pollution. Thus sanitary landfilling has two essential features which differentiate it from crude dumping:

— only sites that will be improved, not degraded, by a change of level, are selected;
— simple engineering techniques are used to control the manner in which the wastes are deposited, so that dangers to public health and the environment are avoided.

The methods of control include two classical requirements:

— wastes must be deposited and levelled in layers not exceeding about 2 metres in depth;
— the whole of the surface of each layer of wastes is covered with soil or other suitable material to a depth of 15–25 cm on the same day as the wastes are delivered to the site.

Limiting the depth of a layer is required partly because of the instability of newly deposited wastes over which vehicles must pass; also to limit the fire risks which arise from various causes. Covering the wastes serves several purposes: it is no longer accessible to flies; attempts by rats to penetrate the covering material are immediately apparent; odours are

14.2 Decomposition in sanitary landfill

Decomposition in a sanitary landfill arises from chemical changes which are brought about by bacteria which are present in the organic content of the wastes when they are collected, and which multiply rapidly, particularly when the wastes are effectively sealed. There are three main types of bacteria which are found in a landfill: the saprogenic, the agent of decomposition; the zymogenic, which are agents of fermentation (they are used in commercial processes such as brewing); and the pathogenic, which are associated with human diseases.

Both the saprogenic and the zymogenic bacteria are found in forms which vary according to the supply of oxygen. There are aerobic types for which oxygen is a necessity. There are obligate anaerobes for which oxygen is a disadvantage, and facultative anaerobes which can adapt themselves to varying supplies of oxygen.

During the first stage of decomposition, aerobic bacteria are dominant, but as the available oxygen declines their work is taken over by anaerobic bacteria; facultative anaerobes will be present at all times.

The bacteria have the ability to create certain colloidal solutions known as enzymes which have the power to break up stable compounds. The enzymes are used by the bacteria to reduce organic matter to a form of nourishment for them and it is this process of breaking down, and making soluble, relatively stable compounds that we know as decomposition. The consequences of all these complex changes include:

- temperature changes within the landfill;
- the production of gases: hydrogen, oxygen, nitrogen, carbon dioxide, carbon monoxide, methane, and sulfuretted hydrogen;
- the production of soluble and particulate decomposition products which can be carried away from the site as a leachate when water passes through the landfill.

14.2.1 Temperature Irrespective of ambient temperature, the internal temperature of a landfill rises soon after the deposit of the wastes as a result of heat emitted by the activities of aerobic bacteria.

The main significance of this rise in temperature is its possible significance in the destruction of pathogens. The conclusions reached by two British investigators, Jones and Owen ("Some Notes on the Scientific Aspects of Controlled Tipping", City of Manchester, 1934) were as follows:

"*. . . it is highly improbable that pathogenic bacteria can multiply and continue to live in a tip. "The factors to be taken into account when considering the likelihood of danger arising from pathogenic bacteria are as follows:*

"The temperature inside a tip rises during the early period of decomposition to a point, in most cases, higher than the thermal death points of pathogenic germs.

At most sanitary landfill sites (the writer would say 99.9%) there is no risk fron methane, which slowly diffuses at a low concentration through the covering material. In rare cases and unusual site conditions, methane may concentrate in buildings near the site.

The most serious risk from sanitary landfilling is that of surface or ground water pollution. This must be avoided by careful site selection, appropriate site engineering, and good operating methods.

14.3 Control of hazards

There are a number of hazards—such as pathogenic organisms, insects, rodents, birds, airborne litter, fire and water pollution—which have to be controlled in a sanitary landfill.

14.3.1 Pathogenic organisms Control over pathogens is dependent upon a rigorous policy of covering the wastes, soon after deposit, with a layer of soil or other suitable material at least 15 cm in thickness. This serves both to isolate the wastes and to retain the heat which is quickly generated during aerobic decomposition.

It is probable, however, that workers at the site will be exposed to the wastes before they are covered. In developing countries the risks to workers by skin contact with wastes may be greater than in the industrialized countries because street sweepings may contain human faecal matter. Protective clothing is necessary, therefore, and should include rubber boots, gloves, and overalls which are changed and washed regularly. The provision of personal hygiene facilities at the site is also important.

14.3.2 Insects The main source of insects will be the eggs of flies which have been deposited in the wastes before they arrive at the site. Most of these will be buried deep in the wastes and will succumb to the temperature increase. Near the surface, however, the rise in temperature will not be so great and the eggs will hatch into larvae; only the provision of an adequate layer of suitable covering material, well compacted, will prevent their emergence and pupation. It is the importance of providing an effective barrier of this kind which has caused the British Government to recommend a covering thickness of 25 cm.

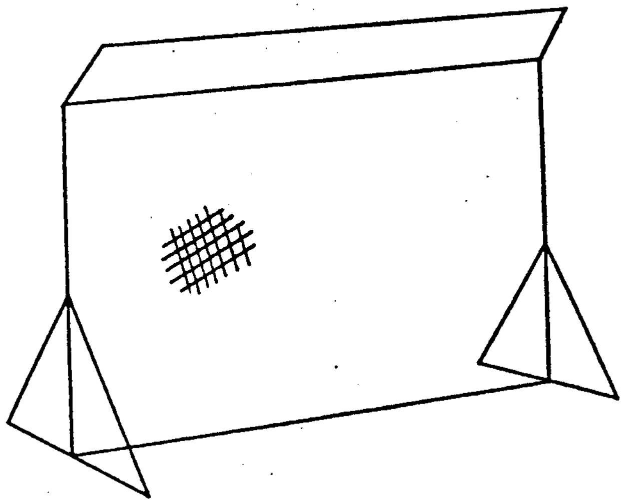
Another obvious advantage of covering is that it denies access to the wastes to flies that are already at the site and thus avoids a major problem of open dumping: continuous cycles of breeding in exposed wastes at the site.

One of the recommended precautions in sanitary landfill is not to permit cans and motor tyres to lie about on the surface. They not only spoil the appearance but when filled with water they encourage the breeding of mosquitoes. Depressions in the surface of the site which permit ponding after rain should be avoided for the same reason.

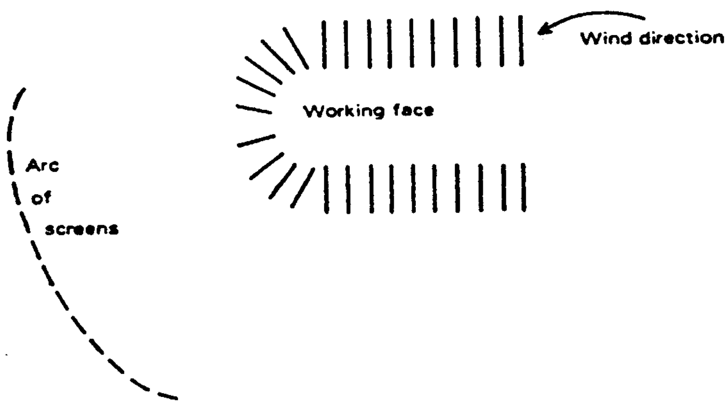
If for any reason these methods of control are not adequate it will be necessary to have recourse to insecticides. They should be used daily as

Figure 17

CONTROL OF AIRBORNE LITTER



Portable litter screen about 2½ metres high, 2½-3 metres long, covered with chicken wire, 20mm - 40mm mesh



A number of screens are used to form an arc the position of which is changed in accordance with wind direction the surface of the fill, percolating through it, and passing over an impermeable base to water at a lower level. Only a proportion of total precipitation emerges as leachate; some is lost by evaporation and transpiration. In the British experiments of 1961 an annual rainfall of 635 mm produced a leachate equivalent to 200 mm. In arid areas there may be insufficient rainfall to create a leachate, but in all other cases the production of leachate from rainfall is unavoidable during the early stages of filling. The quantity of leachate can be substantially increased when upland water drains across the site of the landfill, but the worst case is when a stream crosses the site. The solutions to these problems lie in appropriate site engineering such as:

— diversion or culverting of all watercourses which flow across the site,
— diversion of upland water by means of drainage ditches along appropriate contours,
— containment of leachate arising from precipitation by the construction of an impermeable barrier where necessary, such as a clay embankment adjoining a river,
— grading the final level of the site so that part of the precipitation is drained across the surface, thereby reducing percolation below the level needed to produce a leachate.

Works of this nature will obviously add to the cost of a sanitary landfill project, but it is usual to find that when capitl expenditure is spread over the life of the project the cost/ton is still very much cheaper than for any alternative method of disposal. Furthermore, some of these forms of expenditure, such as culverts or river walls, represent capital assets of continuing value when the reclaimed land is handed over for its final use, perhaps agriculture or recreation.

14.3.9 Groundwater pollution Every proposed landfill site should be the subject of survey and evaluation by a hydrogeologist, and where there is a risk of leachate passing directly to underground water which is the source of a public supply, or to wells, the site must be rejected. The following comments are designed only to indicate the nature of this problem and do not pre-empt the judgement of the local hydrogeologist.

Potential sites can be divided into three main groups:

— impermeable sites,
— sites on which subsoils such as sand and gravel may provide a measure of filtration,
— fissured sites from which a leachate may be able to travel many kilometres.

The classic impermeable site is a clay pit from which there are no pollution risks because the leachate cannot escape.

On sites which provide filtration the British Technical Committee reported as follows:

"Experimental filtration at a rate of about 30 cm per day of the polluted percolates through anaerobic filters of graded sand and gravel produced remarkable results. In a distance of about 7.3 metres practically all bacterial pollution and most of the organic pollution was removed. This was confirmed in full scale tipping. . .
"The experiements. . .The experiments. . . indicated that sub-soils such as sand and gravel would act as an effective filter for bacterial and organic contaminants. For such contaminants as chloride and sulfate, reliance would mainly have to be placed on dilution but generally it is considered this will be sufficient in many cases when the quantity of water abstracted from an underground source of water supply thought to be at risk is related to the quantity of percolate. . ."

On this question the following observations are made in "Sanitary Landfill Design and Operation" (EPA, 1972):

"It is a basic premise that groundwater and the deposited solid waste not be allowed to interact. It is unwise to assume that a leachate will be diluted in groundwater because very little mixing occurs in an aquifer since the groundwater flow there is usually laminar.
"When issuing permits. . . many States require that groundwater and deposited solid wastes be 0.6 to 10 metres apart. Generally a 1.5 metre separation will remove enough readily decomposed organics and coliform bacteria to make the liquid bacteriologically safe. On the other hand, mineral pollutants can travel long distances through soil or rock formations. In addition to other considerations, the sanitary landfill designer must evaluate the: (1) current and projected use of the water resources of the area; (2) effect of the leachate on groundwater quality; (3) direction of groundwater movement; (4) inter-relationship of this aquifer with other aquifers and surface waters."

Where there is doubt as to the characteristics of a proposed site the British Technical Committee suggests the following precautions:

a) Waterproofing the base of a pit prior to tipping, i.e. with puddled clay (or chalk), collection of the percolate and its disposal. . .
b) Rapid tipping of successive layers of refuse in order to utilize its capacity to absorb rainfall and to cover the final layer with a waterproof earth cover with a good cross-fall to provide a ready run-off of rainfall."

Similar advice is given in "Sanitary Landfill Design and Operation":

"An impermeable liner may be used to control the movement of fluids. One of the most commonly used is a well-compacted natural clay soil, usually constructed as a membrane 30 to 90 cm thick. It must, however, be kept moist.
"The use of an impermeable barrier requires that some method be provided for removal of the contained fluid."

14.4.2 Location and access The solid wastes management authority can then evaluate the sites proposed by the town planners, using the following criteria:

1. The location should be as close as possible to the built-up city area in order to reduce transport cost. (At Rs 0.60/ton/km, an extra 3 km further from the city would add 6 km to every journey, equivalent to Rs 3.60/ton of wastes.)
2. The site should be close to a road which is capable of handling the traffic generated by the landfill site.
3. Sites will be preferred at which the nearest dwelling is at least 200 metres distant. However, there are many examples of nuisance-free filling much closer to buildings when operating standards are high.
4. Large sites enable capital expenditure to be spread over a greater tonnage of wastes, thereby reducing unit cost.

14.4.3 Water authorities The sites which have been selected by the solid wastes management authority must now be submitted to the water supply authority, and also to the rivers authority if that is a separate body, for hydrogeological evaluation. The judgements of the water authority are likely to fall into three categories: approval, disapproval, or qualified approval. Qualifications are likely to relate to site engineering of a protective nature, such as drainage,or to the operating method, or even the nature of wastes that may be deposited.

14.4.4 Final selection of sites The final choice of a site or sites will probably be based on cost which will comprise three main elements:

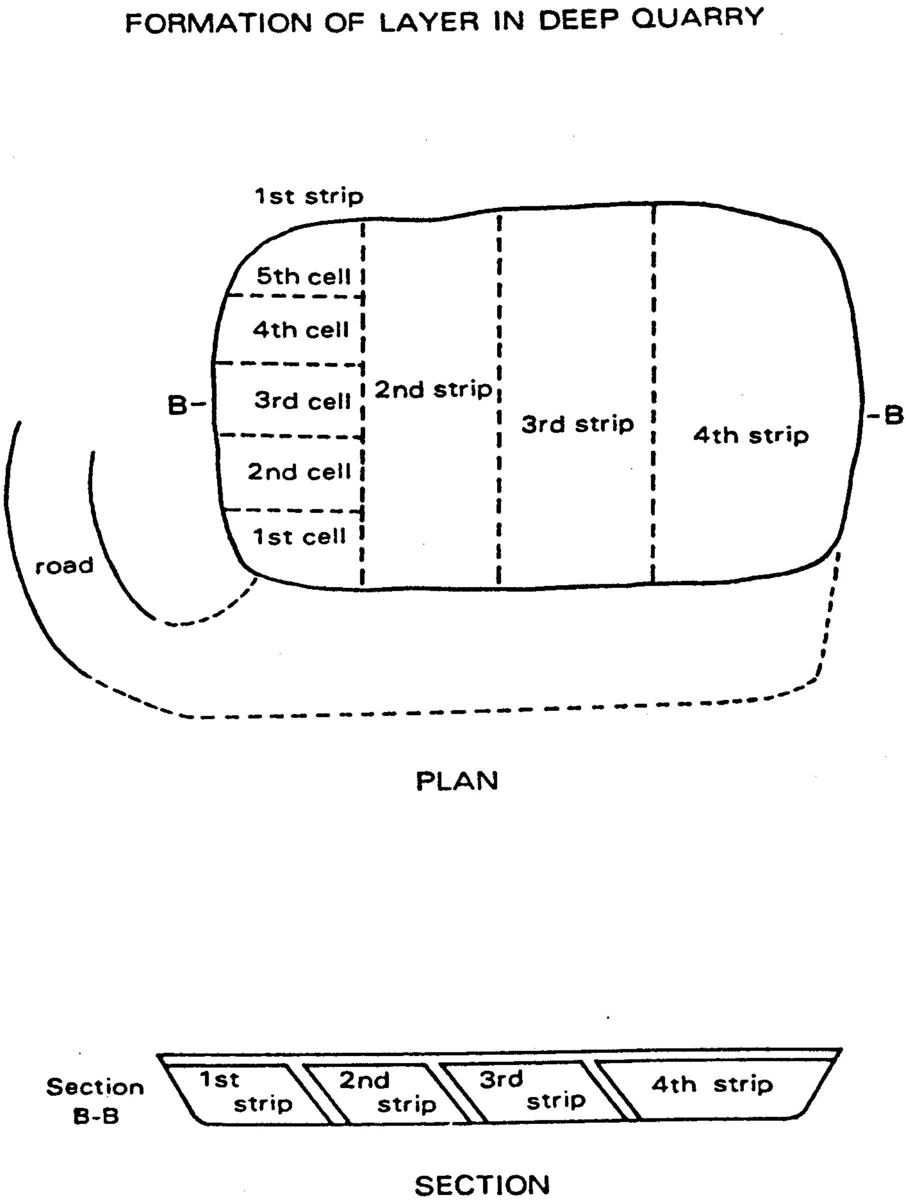
— site engineering to avoid water pollution,
— capital works for site operation, such as a site office,
— operating costs: labour, purchase of covering material and road material, stores, and plant operation if mechanized.

When comparative costs of alternative sites are being judged, it is important to take into account the inter-relationship of transport cost with refuse collection; for example, transport savings by using a near site may out-weigh a higher expenditure on site engineering. For the same reason, the diseconomy of scale arising from multiple small sites as against one large one may be more than offset by savings in transport cost.

14.4.5 Site acquisition It is implicit in sanitary landfilling that a site will be of very limited utility, if any, before reclamation, and will be capable of fulfilling its planned ultimate use afterwards. Thus the land value of a potential site should be low and the value should rise after reclamation. For this reason it is highly desirable that the local authority should buy the land outright in order to profit directly from the ultimate increase in value. Many useful sports fields have been acquired in this way at very low cost, and reclaimed land has sometimes been sold at a good profit for agricultural use.

Figure 20

FORMATION OF LAYER IN DEEP QUARRY



— shed for small stores, tools, etc.
— garage for earthmoving plant, if used,
— shed for salvage, if recovered on site,
— site identification board.

This area, or at least that part of it on which the temporary buildings will be located, should be formed from inert materials if it is at raised level.

At small sites having relatively short lives the erection of temporary buildings for such purposes as office, toilet and small stores can be avoided by using a caravan which can be towed from one site to another.

14.5.3 Plan of operation The most important feature of the plan will be the main site road which should permit access to the most distant part of the site in any kind of weather. This could be a spine road crossing the centre of the site, or it could follow one of the boundaries. In the case of a former quarry, a road to the bottom level is likely to be in existence. On a level site, the road must be constructed at raised level. In a valley site or a deep natural depression, the road must be taken to the lowest two-metre contour to gain access to the lowest level where the first layer will be formed. This road is normally formed from wastes which are topped, after normal covering, with hardcore (broken bricks) old road metal, or similar material. When it is brought into use this road requires to be continuously repaired as it settles, and after about a year it can be water-proofed with a layer of bitumin.

A deep site should be surveyed and a contour plan prepared; two-metre contour lines would indicate each successive layer of wastes.

To ensure the orderly progress of filling and covering, each layer should be constructed from a number of side-by-side strips (sometimes called fingers), the width of a strip depending upon the number of trucks which would have to unload simultaneously at the working face. The width of the working face, which is the same as that of a strip, is calculated in the folllowing way:

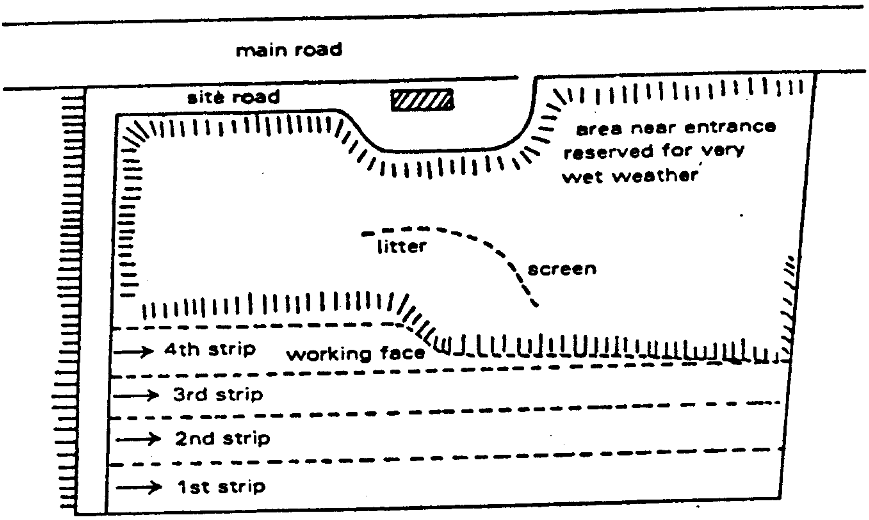
— At a 250 tons/day site it has been estimated that 70 loads will arrive over a period of 8 hours.
— This is equivalent to 9 vehicles/hour, or one every 7 minutes.
— If unloading time is 10 minutes, 1.5 trucks discharge simultaneously.
— But this is the average rate and allowance has to be made for peak periods. This can be determined locally by examining vehicle times.
— Assume it is necessary to allow for 4 trucks at peak periods, then the width of the working face should be 4×6 metres = 24 metres.

In practice the necessary width of a strip is likely to range between the minimum of 6 metres at a site handling a very small tonnage to about 30 metres for 200-300 tons/day. When the input to a site exceeds this amount multiple working faces are recommended to minimize traffic congestion.

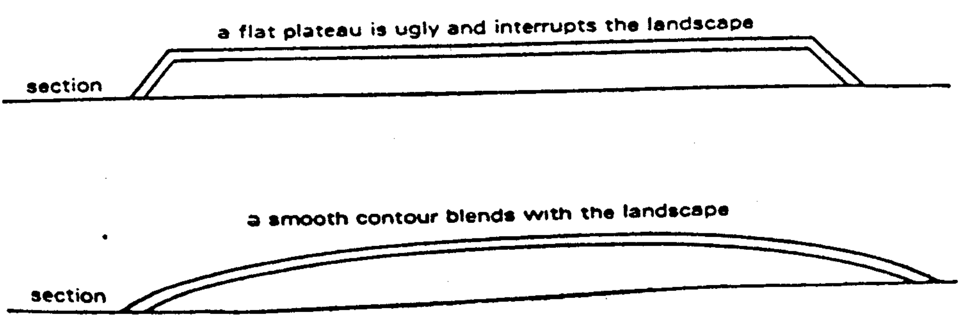
This is an appropriate point at which to refer to the importance of using vehicles with tipping gear, either hydraulically operated or manually operated by worm and nut. Vehicles which have to be unloaded by means

Figure 21

PLAN OF OPERATION FOR A LEVEL SITE



STAGES
1. Entrance area and site of building filled with inert wastes
2. Site road formed from wastes, covered 25 cms soil plus 30 cms hardcore; waterproofed after 1 year.
3. First strip; wastes covered 25 cms
4. Subsequent strips formed
5. Cultivate strips 1 and 2 when work commences on 4th strip



One that is well constructed can have an in-place density as great as 885 kg/cu.m. . . generally 472–590 can be achieved with moderate compaction effort."

From "Controlled Tipping" (Bevan, Institute of Solid Wastes Management, London):

"In density tests, excluding covering material, at Sunderland in May 1963 Jackson, D.W., recorded the following:

Density as tipped from vehicle and after pushing over, but before compression by traffic:	*270kg/cu.m*
Density after 3 days	*628 "*
Density after 1 year	*760 "*

From "Garbage Disposal for Calcutta City" (National Environmental Engineering Research Institute, India, 1970):

". . . a number of scattered sites where dumping was done six months earlier were chosen. . .where a one cu. metre trench was excavated. The material taken out was then weighed to get the density. . . The average is adopted. . . the table indicates that even without any compaction equipment it is possible to get a good density within six months. This is essentially due to. . . the typical characteristics of the material. . .

Density of refuse arriving at various disposal sites:	*range, 518–573 kg/cu.m*
Density of dumped refuse (6 months old)	*average 1 128 kg/cu.m*

14.6.2 Other forms of compaction From the figures quoted above it would appear that high density wastes which are typical of developing countries do not require deliberate initial compaction. (In the few developing countries where wastes are low in density, compaction equipment may be desirable but in these countries the cost of the equipment does not present a problem.)

In any case, compaction takes place in other ways. One is by the repeated passage of wheeled traffic over the strip being constructed.

The process of decomposition is the main agent of compaction and stabilization. Bevan describes this in terms of wastes which have about 40% vegetable/putrescible matter and about 40% paper, but his argument is equally valid for the wastes of developing countries where vegetable/putrescible matter may range from 50% to 80%.

"The statement has often been made that lighter, bulkier refuse takes up more tip space. While this is true in the short term. . . this assumption ignores the natural phenomenon of decomposition—the reduction of complicated substances to simple elements and the reduction in volume achieved. . . . 80% or so of the refuse will be in a form which will

after filling: first to strip the topsoil and later to replace it at higher level, because few subsoils are entirely suitable for primary covering over which vehicles have to be driven.

14.7 Manual Operation

Manual operation—that is, without the use of earth-moving equipment—could be fairly effective if proper care is taken in the selection of the site and in the formation of strips.

14.7.1 Access As with all other methods of operation, an all-weather access road must be provided first, from the nearest point on a main road to the point at which filling by wastes is to commence. This road is usually built from waste materials such as construction wastes, broken and rejected bricks or old road metal on a bed of ash or clinker to provide drainage. After the road has been made, a small stock of these materials must be kept available for day-to-day repairs such as filling depression caused by traffic.

14.7.2 Pegs The position of the first strip to be raised should be defined by two rows of pegs driven into the ground, and the final level of the first layer should be indicated by occasional posts with cross pieces which can be used for sighting. Unless guidance of this kind is provided it will be found that operations allow the depth of the fill to increase as the strip extends.

14.7.3 Formation of strips The most effective tool for forming an embankment from wastes is a three-tine "drag", or rake, with a handle up to two metres in length. The size and form of the tines are similar to those of a fork used for digging, but the tines are at right-angles to the socket for the handle. These tools are easily forged by a blacksmith and the handles, which should be light, yet strong, can be made from a wide variety of natural materials; ash is preferred in Britain, but cane may be suitable too.

The vehicle delivering the wastes should be reversed to a point as close as possible to the working face, to minimize the distance over which the wastes have to be moved by hand. (The importance of vehicles being equipped with tipping gear has been stressed earlier.) To reduce the risk of the vehicle reversing too far, a strong, heavy, bumper bar should be placed at the point where the rear wheels are intended to stop. This is usually a baulk of timber such as two railway sleepers bolted together.

To avoid the rear wheels of vehicles sinking into the newly deposited wastes near the working face, it will probably be necessary to cover a small area with steel sheets or old railway sleepers.

If the wastes are well placed, they will form a heap above the filling level, but immediately adjacent to the working face. Very little lateral movement will be necessary, and most of the heap can be dragged down by the men on the face, a comparatively easy task assisted by gravity. To accomplish this, however, they need to stand in the wastes and protective clothing should be provided.

If there are hollow containers such as old oil drums in the wastes, these should be placed at the toe of the face in an upright position and filled with wastes; otherwise they would cause voids and the risk of uneven settlement.

As the face advances, the flanks are formed by dragging the wastes to an angle of about 45°. The only occasion on which it is necessary to form the working face to a specific angle is when it is about to be covered, which could be at the end of each working day or at less frequent intervals. The angle of the face at the time of covering should be as steep as possible in order to minimize the amount of covering material used.

From time to time during the day covering material should be delivered to the site, the volume required being between one fifth and one seventh of the volume of the wastes after formation in the fill. The density of the wastes at this stage will be at least 50 per cent higher than when delivered to the site even if the initial density is high.

If the new wastes have been covered by steel sheets, these are temporarily removed while covering material is being spread to a thickness of at least 15 cm and preferably up to 25 cm. The best tools for this work are shovels and wide garden rakes with short tines. The flanks are also covered to a similar thickness, and this covering should be beaten down by the backs of shovels or by specially fabricated wooden beaters with long handles.

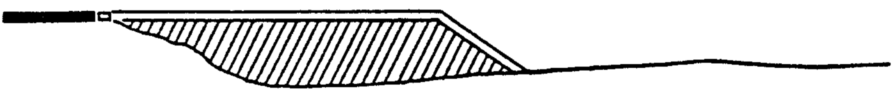
14.7.4 All-weather operation Prolonged heavy rain is the only real obstacle to the smooth operation of the procedure that has been described; if the surface of the embankment becomes waterlogged then there is a risk that vehicles will sink in. When periods of heavy rainfall are a feature of the climate, it is advisable to provide a portable roadway across the strip in the form of old railway sleepers or steel sheets. Alternatively, and provided that this does not inhibit the ultimate use of the reclaimed site for its planned purpose, a hardcore road can be laid to within about 50 metres of the working face. Portable road surfacing can then be used only for the final approach.

It is the custom at many sites to reserve an area close to the original access road for emergency use during periods when, despite all the other precautions, it is temporarily difficult to cross the site. This can happen if a vehicle breaks down on a single-track roadway.

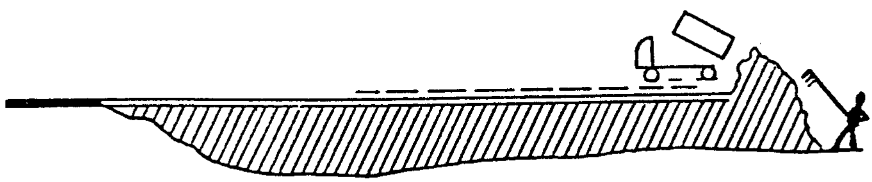
It is necessary to be prepared to recover vehicles one or more wheels of which have sunk up to the axles. Heavy jacks and timbers are necessary. The vehicle is jacked up, using the timbers to spread the load; the cavities caused by sinking of the wheels are then filled with hardcore. It is then usually possible to drive the vehicle out, with towing assistance from another vehicle if necessary.

14.7.5 Labour required The writer has clear recollections of three sites which were operated in the above mann , and the staffing ratios were as follows:

4. The heaps of wastes are levelled by a three-tine drag (or rake) with a handle about 2 metres long and the flanks are formed to an angle of about 45°. Levels and strip width are guided by pegs driven earlier.



5. Every day the levelled wastes and the flanks are covered by between 15 cms and 25 cms of soil, sand, ash or composted wastes etc. Daily, or weekly, the working face is covered to form an enclosed cell of wastes.



6. Always take the vehicle right up to the working face to avoid dumping wastes on covered areas. If vehicles sink in, extend the hardcore road as far as possible, then use railway sleepers laid transversely, or steel sheets, to form a track over the newly deposited wastes. Always provide a heavy bumper bar at the point where vehicles unload.

countries. Hence the importance of seeking sources of covering material that can be obtained without cost, such as ash from power stations, soil from excavation, and other kinds of inert industrial wastes. In Britain it has often been found that if free disposal facilities are offered to the producers of these useful kinds of wastes, the level of expenditure on the importation of covering material can be greatly reduced.

Also of significance is the fact that a disposal cost at the higher figure of Rs 7.8/ton represents only Rs 1.17/inhabitant/year at the given rate of wastes generation. This is about 15% of current average expenditure on solid wastes management services in the South-East Asia Region of the World Health Organization; it is a level of expenditure that could be sustained in the poorest countries.

14.8 Mechanized sanitary landfill

Earth-moving machines are tractors (i.e., motor vehicles which are designed to operate over unmade ground by means of low ground-loading and high torque) which are equipped with devices for excavating, pushing, lifting and carrying solid materials. They can be classified in two ways: the distance over which they can operate economically and whether they are wheeled or tracked vehicles.

14.8.1 Characteristics of machine types The blade of a bulldozer is designed for pushing; it is concave so that the lower edge of the blade will excavate when depressed below ground level. The blade can be raised above ground for levelling a thin layer of covering material. Because of its very slow speed it is economical only when operated over very short distances, never more than 100 metres.

The front-end loader is a machine with a hydraulically operated bucket, having a capacity between 0.5 and 3 m^3, which is used for excavating, lifting and carrying; it can also be used for pushing, although it is less efficient than the bulldozer. The economical transport range of a tracked front-end loader is less than 100 metres, but a wheeled loader may be economical up to twice this distance because of its higher speed. At greater distances the front-end loader is used to load vehicles which shuttle between the point of excavation and the working face.

The scraper, which may be self-propelled or towed by a tractor, is a form of bowl mounted on wheels; the cutting edge of the bowl can be adjusted to operate below the level of the ground over which it is travelling. The material sliced off gradually fills the bowl; the contents can be discharged as a thin layer for covering purposes, or built up into a large heap for storage. Scraper capacities range from 2 to 30 m^3 and the economical range of operation is up to 300 metres.

The dragline is a cable-operated bucket carried on a boom. The basic machine is tracked but operates from a stationary position. It is often used for excavating wet material; for example, in the reclamation of marshland the machine would be sited on the raised area and would excavate from the low level, lifting and depositing the excavated material behind it at the

For 100 tons/day at initial density 330 kg/m³

Essential tasks at all sites:	
Formation of delivered wastes*	300 m³
Spreading primary cover on wastes	40 m³
Additional tasks when cover obtained within site:	
Excavating and transporting primary cover	40 m³
Excavating and storing topsoil, say	30 m³
Total volume to be handled	410 m³

Out of a total of 410 m³ to be handled, 340 m³ is short-distance pushing and grading. Thus, for 80% or more of the total work a bulldozer is the most suitable machine. When all covering material, including topsoil, is to be delivered to the site from an external source, then only a bulldozer will be needed. The capacity of a bulldozer for the essential tasks is of the following order:

Power Rating (hp)	*Capacity (tons/day wastes input)*
40	100
80	200
180	400

When covering material is to be excavated from the site, it is usually necessary to employ a second type of machine. For heavy duty excavation a tracked front-end loader is preferred but if vehicles have to be loaded a wheeled loader is better. The performances of these machines vary widely, but the following is an indication of the rate at which vehicles can be loaded:

Item		*Equivalent wastes input*
0.5 m³ bucket	100 m³/day	150 tons/day
2.0 m³ bucket	360 m³/day	500 tons/day

If a front-end-loader is used to transport excavated material in the bucket direct to the working face, then output declines in proportion to the distance travelled.

14.8.4 Mechanization in relation to scale of operation The chart on page 139 has been adapted from a guide to sanitary landfilling prepared by New York State. It is interesting for two reasons: the first is that rising economy of scale appears to cease after about 250 tons/day; the second is that unit cost rockets below about 50 tons/day.

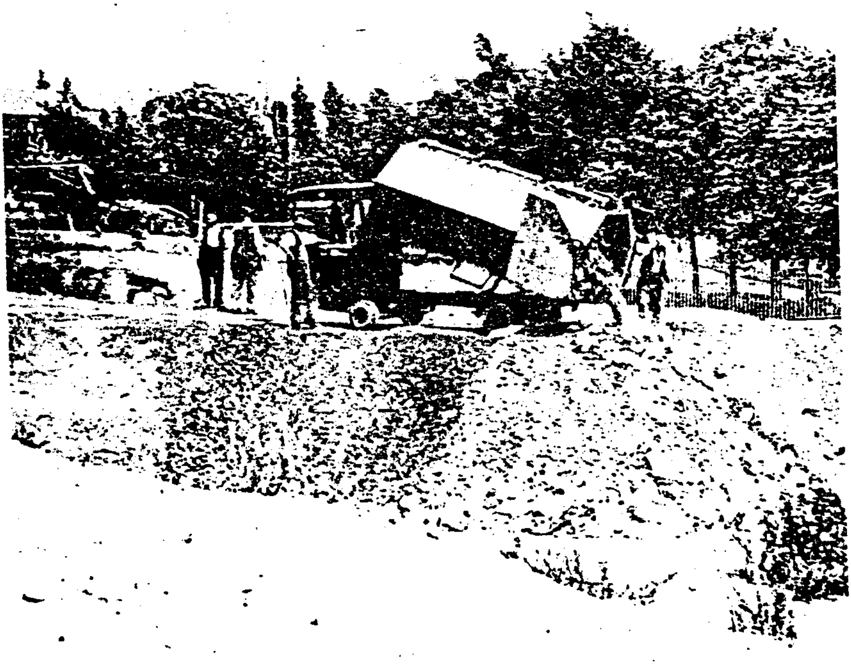
*The only significant difference compared with manual methods is that flanks are formed to a slope of 1 : 3 to permit the machine to drive up and down them in spreading cover.

performance limitation of this machine is in the distance over which bucket loads can be transported, because of its slow rate of travel.

14.8.5 Possible operating costs There are too many national and local variations in wages, wastes, energy costs and site conditions to be able to suggest firm costs, but it will be useful to indicate possible cost scale in given situations. The plant operating costs used below are typical for India in 1976 and include amortization, repairs, fuel and operator. Labour costs are taken as Rs.15/day inclusive of oncosts.

250 tons/day site (all cover obtained from with site at a distance not exceeding 600 metres from working face:

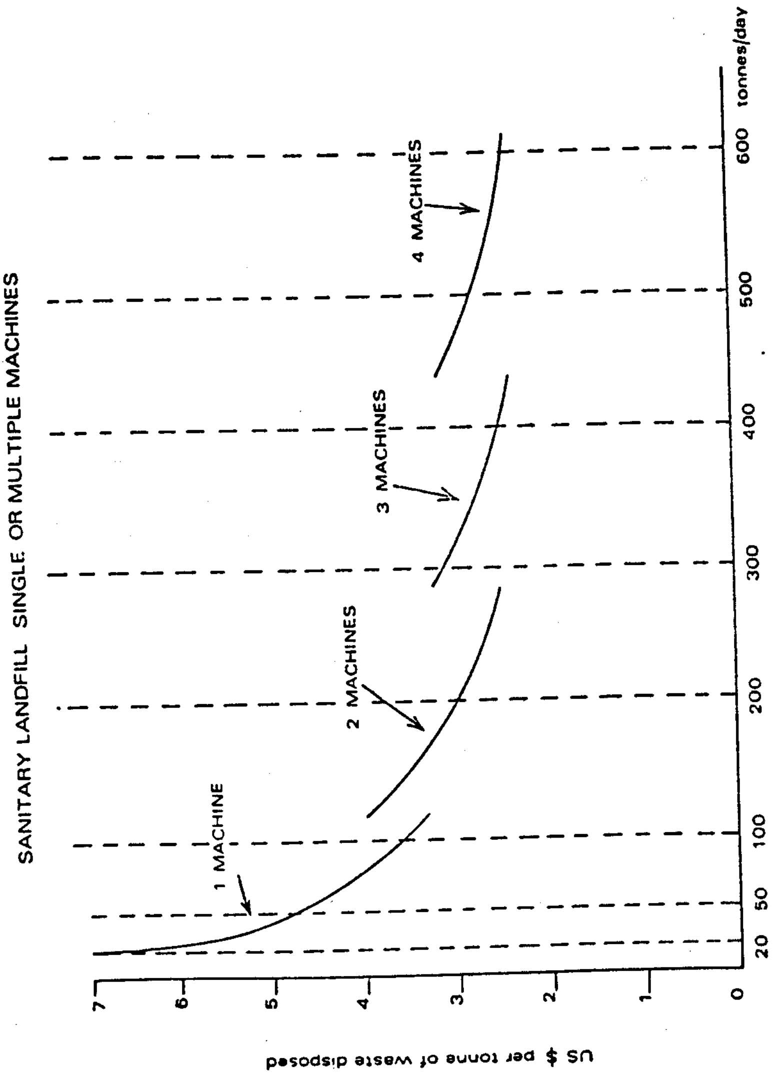
	Rs/day
1 — 180 h.p. bulldozer (285 000/yr.)	950
1 — 2 m^3 wheeled front-end loader (200 000)	660
2 — transport vehicle (2×50 000)	330
Labourers 10	150
Total cost/day	2 090
Cost/ton	Rs 8.36



17. This British site is of interest because the vehicle has very small solid-tyred wheels (1935) but has successfully negotiated the track formed from steel plates.

Figure 24

SANITARY LANDFILL, SINGLE OR MULTIPLE MACHINES



Adapted from "Sanitary Landfill" New York State Department of Environmental Conservation. (1971)

14.9.1 Water-filled sites It is quite common to find that a low-lying site which is hydrogeologically safe because of impermeability contains a body of static water caused by precipitation and surface drainage. It has been accepted that only inert wastes should be deposited in water because of aerial pollution from hydrogen sulfide which would be caused by the deposit in water of organic wastes.

Experiments to control aerial pollution caused by decomposition of wastes deposited in water have shown that the problem increases in relation to ambient temperature; the risks are probably much greater therefore in tropical than in temperate countries.

Impermeable water-filled depressions can be pumped dry after which filling can proceed as for a normal site. When the water area is very large, lagooning is recommended. The water-filled area is divided by bunds formed from inert wastes into areas of 0.5 ha or less. Each lagoon in turn is pumped dry and filled.

14.9.2 Ravines Sometimes it is desired to fill narrow, deep ravines. Conventionally a road should be cut to within 2 m. of the lowest level, but the cost may be excessive in solid rock. One site was seen where a ravine 30 m wide by 20 m deep was filled in a single layer. The top surface of the wastes was covered with 20 cm of soil at the end of each day, but it was impossible to cover the working face. The rate of input, however, was high enough to advance the face several metres/day so that all wastes were covered daily by new wastes. The prevailing temperature was about 22°C, but there was no evidence of fly breeding on the site, presumably because the sides of the fill were enclosed by rock and the top by earth, and the period of exposure of wastes on the face was too short for larvae to emerge. This appears to be a situation in which some of the rules can safely be broken. Care should be taken to ensure that water supplies are not endangered by fissures in the rock. More than the usual amount of long-term settlement should be expected in such deep fills.

14.9.3 Desert sites and trenching method Deserts where the soil is very deep and is free of rock out-crops lend themselves to sanitary landfill by trenching. The writer has no practical experience of this method, which was developed and widely used in USA, and the following description is taken from "Sanitary Landfill" (*American Society of Civil Engineers, Manual* No. 39, 1959).

> *"The trench method is most often used when flat or gently sloping land areas are available. It is adapted for use on terrain which can be trenched by normal earth-moving equipment, preferably without intersecting groundwater. . .*
>
> *"Construction of a trench fill is begun by digging a trench along one side of the area to be used for the sanitary landfill, and placing the excavated earth as a berm adjacent to the trench on its limited side. It is desirable that the trenches should be dug so as to be self-draining. Refuse is deposited*

and compacted in sufficient quantity to fill the trench and to extend somewhat like an area fill to the elevation of the top of the berm. The exposed, or dumping face, stands at the angle of repose of the refuse.

"The fill begins at one end of the trench and develops progressively along its length. It is covered daily with earth dug from an immediately adjacent parallel trench in which the next fill is to be made. The top is given a heavy cover, while the working face is merely closed for the night with a light covering of soil approximately 15 cm thick. When completed, a sanitary landfill constructed by the trench method consists of a series of long, narrow, refuse cells. Below the original ground level the cells are separated longitudinally by ridges or ribs of undisturbed soil, while above the original ground surface sloped or wedge-shaped diaphragms of cover material serve as separators. The top of the finished fill appears as a plane surface of earth at an elevation somewhat higher than the original or surrounding terrain. . . .

"In cases where trenches and fills are both shallow and the volume of refuse is not large, all operations involved in constructing a sanitary landfill by the trench method may be performed by use of a crawler-type tractor equipped with a front-end shovel attachment. In Columbus, Ga., such equipment is used in digging trenches 1 metre deep and in placing and covering a 1.3 metre refuse fill. . .

"There is no uniformity of practice regarding the depth and the width of the trench used. . . .In some literature it is suggested that trenches be 1 metre or more in depth and from 2 metres to 5 metres wide. However, some cities use much deeper and somewhat wider trenches.....cities in California use trenches from 2 m to 4 m deep and from 4 m to 7 m wide. Separating ridges vary from 1 m to 4 m. . . .

"It is general practice to use all of the soil excavated from a trench to cover the refuse deposited in the previous adjacent trench. . . .available cover material is usually sufficient to provide a final cover of from 1 m to 1.3 m of compacted soil on the top of the refuse cell, and from 0.6 m to 1 m on the slope which forms the transverse wall of the cell. . . excess cover material may be used. . . to cover an area fill of rubbish at a separate site."

14.9.4 Small communities The manual method of operating sanitary landfill as described earlier is usually appropriate to the needs of villages and small towns. For example, one man could operate the system on a scale of 3–5 tons/day, digging all necessary covering material from the toe of the flanks; this would be equivalent to a population of 5 000 to 10 000.

It has sometimes been suggested that a regional authority could serve the needs of scattered communities by operating a trench-digging service if the terrain was suitable. An excavator would be taken from site to site on a low-loader, and it would excavate a trench at each site with a capacity sufficient to contain the wastes of the community until it returned, perhaps several weeks later. At each site a man would be employed full time or part time, according to need, and he would use the excavated material at the side of the trench for covering wastes tipped into it.

14.9.5 Salvage at landfill sites Scavengers are usually attracted in large numbers to uncontrolled dumps where the wastes are exposed and easily picked over. At sanitary landfill sites, however, only the wastes on the working face are accessible, and it is much easier to prevent scavengers from operating.

Salvaging by employees, however, is still practicable and if they are permitted to sell the recovered materials on their own behalf, salvaging may take precedence over other aspects of work and the situation may get out of hand. The following extracts from a report on a sanitary landfill site illustrate this problem:

". .the project has been excellently conceived and planned. . . .the first section has been filled in two layers. . . the surface was level and totally covered . . . .(but) the site was heavily littered with wind-borne litter. . .Enormous exposed heaps of salvaged materials were stored on the raised section: tins, card-board, bottles, dirty mixed paper, and mattresses. These materials were heavily infested with houseflies, and the tins and dirty paper contained large amounts of putrefying matter which would encourage oviposition. Fly breeding was occurring on a large scale. . . "Incoming refuse was being deposited in a series of heaps on the coverec surface extending backward 50 m or more from the face. This wa apparently done deliberately in order to spread the refuse over a large are to expose it to the maximum extent for hand picking of salvage. Th disadvantages of this are:

- *work of the bulldozer is increased as refuse has to be moved over a greater distance,*
- *fine organic matter containing fly larvae is left behind on the covered surface, and pupate,*
- *litter such as plastic sheet is left behind and spoils the appearance of th covered surface."*

This situation is not at all uncommon and the best way to avoid it is to organize the salvaging as part of the operation. A system which worked well in the United Kingdom with manual landfill operation was as follows:

All recovered materials were sold by the city and 25% of the income was distributed among the men employed at the site as a bonus to encourage their co-operation.

All salvaging took place on the sloping working face during the process of levelling the wastes by drag. All the materials picked out were immediately placed in boxes at the toe of the face, and full boxes were taken to a salvage store.

In this store, paper was immediately baled in a hand-baling press making bales of 60–100 kg.

A trailer was provided for the storage of cans and this was towed to a merchant every 3 days before flies could breed.

If necessary, the salvaged materials were sprayed with insecticide.

Salvage was sold only to approved outlets, for example, rag merchants or bottle merchants having satisfactory cleansing facilities.

14.10 Model code of practice

With a master plan for disposal sites, a plan of operation and a detailed schedule of operation practice, a fairly effective model code of practice could be laid down.

A. MASTER PLAN FOR WASTES DISPOSAL SITES

1. The solid wastes management agency should identify:

- Sources of solid wastes within its area,
- rates of wastes generation,
- constituent analyses and densities of wastes,
- projections for at least 10 years for population growth, wastes generation and characteristics,

and should make outline plans and comparative cost estimates for viable alternative disposal methods.

2. The land-use planning agency should review the area within the city boundary, and up to 10 km outside the boundary where necessary, and identify sites, manmade or natural, which would be *improved* by landfilling. The planning agency will evaulate potential sites in terms of:

- ultimate use after filling; parks, playgrounds, sports grounds, agriculture, industry,
- the quality of environmental improvement which would result from filling,
- risk of pollution transfer during filling,
- ecology of the area,
- social and economic factors,

and will submit selected sites to the water and river authorities.

3. The water supply and river authorities will evaluate potential sites in relation to the hydrogeology and drainage of the area, and will reject sites where underground source of water would be at risk. Where appropriate, the water and rivers authority will define the measures that must be taken to avoid pollution of surface water and to control the production of leachate.

4. The solid wastes management, land-use planning, and water and river authorities should maintain a continuing relationship with the aim of ensuring a 10-year rolling programme of landfill sites.

B. PLAN OF OPERATION

1. Site survey. Each selected site should be surveyed and a plan prepared on a scale of about 1:2 500 showing:

these measures. The width of a prepared approach should be single or multiple track according to the frequency of traffic movements.

3. *Formation of wastes.* Wastes unloaded at the working face should be formed into a continous embankment 2 metres high after initial compaction, and having a width of approximately 6 metres per véchicle when more than one vehicle has to unload at the same time. The side slopes (or flanks) of the strip being filled should be 45° for manual operation or 30°, or less to the horizontal,. for mechanized operation.

4. *Covering of formed wastes.* The top surface and the flank(s) of the strip being formed should be covered progressively with a layer of soil or other suitable sealing material not less than 20 cm thick. This should be beaten flat and smooth if applied manually, or consolidated by repeated traverses if a machine is used. At the end of every working day, covering should be completed on the top and flank(s) of the fill. At intervals, which may be daily, or not less frequent than weekly, the forward slope of the working face is to be formed and covered in the same manner as described for the flanks, in order to achieve a cellular construction.

5. *Deep sites.* If the required total depth of fill exceeds two metres, then, the site will be filled in multiple layers, and to facilitate natural settlement and the dispersal of gases, a long interval, never less than three months, should be allowed to elapse before one layer of wastes is covered by another.

6. *Hollow articles.* Articles such as large hollow containers should be crushed by being placed in the path of a tracked machine, or should be put at the toe of the working face in an upright position and filled with other wastes. This is to minimize the creation of voids within the fill, which would lead to uneven settlement.

7. *Offensive wastes.* Any load which consists mainly of fish wastes, abattoir wastes, carcasses of animals or medical wastes*, should be deposited at the lower level, immediately in centre front of the advancing face, and should be covered with other wastes so that no part of the offensive wastes is within one metre of the top surface of the hill, and is not less than two metres from a flank.

8. *Litter control.* Portable wire mesh screens should be erected in an arc of sufficient length to trap airborne litter blown from the working face.

9. *Manning levels.* Adequate staff should be provided to ensure compliance with all requirements of this code. For manual formation of the

*Hospitals and clinics should be equipped with properly designed incinerators for the treatment of pathological wastes, and sanitary landfill should not be regarded as a normally acceptable disposal method for such wastes. In the absence of proper facilities the above method may be used provided that the wastes are delivered to the site in impermeable disposable packages which are not opened. Hypodermic syringes should always be broken before being discarded.

CHAPTER 15
URBAN WASTES AS A SOURCE OF COMPOST

15.1 Introduction

In nature, dead vegetable and animal matter is decomposed, where it happens to fall, by bacteria; the products of decomposition add to the fertility of the soil by improving its physical properties for the support of plants, and by the provision of plant nutrients. A similar process takes place with animal excrement, and throughout history, until the invention of artifical fertilizers, farmers have been dependent upon organic manures, derived from animal excrement and decayed vegetable, for the maintenance of soil fertility. There are many parts of the world, particularly villages in tropical and sub-tropical regions, where farmers still rely almost entirely on organic manures.

A major constituent of domestic solid wastes is dead animal and vegetable matter, mainly in the form of kitchen wastes and garden wastes. Urban areas generate domestic and shop wastes on a large scale, between 300 and 800 g/person/day. At the mean of this range, a city with a population of one million would generate over 500 tons/day. At least 25% and up to 75% of this weight comprises vegetable and putrescible matter.

Over the past 50 years the disposal of such urban wastes has become an increasingly difficult problem: landfill has always been the most common disposal method and is likely to remain so, but when sites close to a city have been filled up additional expenditure is necessary to transport the wastes to more distant sites. Thus it has become more and more important to discover treatment methods which reduce the volume of wastes to be accommodated on scarce landfill sites. Incineration is an effective solution, but it is expensive for any kind of waste and it is most expensive for wastes having a high proportion of vegetable and putrescible matter, because this implies a high moisture content and a low calorific value.

It is natural, therefore, that the possibility of converting urban wastes, or a substantial proportion of them, into organic manures, should have attracted interest over many years. Such a process is known as composting and has two essential features:

— the use of methods and equipment which facilitate decomposition of the organic content under controlled conditions, so as to avoid risks to health or the environment, and

Forty tons of compost may occupy a volume of 60 m^3; thus its application to farmland involves substantial labour cost. Where mechanized farming is practised manure-spreading machines have been found to operate effectively with compost.

Because the time of applying compost is determined by the cropping cycle, demand is usually seasonal, A compost plant may therefore require storage capacity for its product for several months.

15.2.3 Place of compost in agriculture There are two situations in which the production and use of compost may be of great importance to the agriculture of an area:

— for bringing into cultivation marginal land suffering from organic deficiency; such areas are most common in tropical climates where hot sunshine tends to destroy organic matter;
— in areas where artifical fertilizers are in short supply or are very expensive.

In relation to agriculture as a whole, these situations are exceptional. (Examples of the former can be found in West Asia where composted urban wastes, usually in combination with irrigation schemes, have been used as a source of humus to aid cultivation of former desert areas; India and China provide examples of countries which tend to use composts primarily, but not exclusively, as a source of nutrients.)

In most agricultural situations, however, organic soil deficiency is not apparent, and farmers are conditioned to the use of artificial fertilizers, the nutrient content of which is known with certainty, unlike composts which may vary widely from batch to batch. Thus, although compost has different properties from artificial fertilizers and is, in fact, complementary to them, it usually has to be marketed in competition with them, for farmers have a limited budget for fertilizers.

It is necessary, therefore, to satisfy two requirements before compost will be accepted into regular use by a farming community:

— it must be demonstrated beyond question that the use of compost produces larger crops of better quality than is possible by the use of artificials alone;
— the price of the compost must be low enough to compensate for its higher transport cost and the greater labour cost of applying it to the land, but the price can also reflect at least part of the value of the nutrients in terms of equivalent artificials.

15.2.4 Importance of agricultrual authorities It will now be apparent that there are two parties involved in a policy of composting urban wastes:

— the agricultural authorities, who should determine the extent to which compost may be required for organically deficient areas, or as a primary source of nutrients, or for agricultural use in general;
— the solid wastes management authority, whose function is to collect the wastes and produce from them the necessary quantity of compost.

Constituents	*% by weight*		
	Indian	*Mexican*	*British*
Essential to compost:			
vegetable/putrescible matter	75	55	28
Acceptable for composting:			
paper	2	15	37
inert below 10 mm	12	0	9
Compostable total	89	70	74
Salvageable constituents:			
paper (also included above)	4	15	37
metals	0.4	6	9
glass	0.4	4	9
textiles	0.7	6	3
plastics	8.5	4	3
Total of potential salvage	6	35	61
Contraries:			
misc. combustible	0	2	1
misc. incombustible	7	6	1
Total of contraries	7	8	2

In this table paper has been included in both the compostable and salvageable categories; it is likely that some proportion of it would be salvaged. The practical recovery rate for saleable constituents ranges between 20% and 60% of the potential figures above. When a correction is made for these factors, the following realistic summary emerges:

Final destination of constituents	*Indian*	*Mexican*	*British*
Compostable*	88	65	64
Salvageable	2 or less	15	22
Contraries, including salvage not recovered	10	18	14

15.3.2 Potential compost production From the physical analysis described in the preceding section it is possible to arrive at an estimate of the weight of compost which could be produced from each ton of wastes. For the Indian wastes the estimate would be as follows:

Each ton of wastes received contains	880 kg compostable matter
@ 50% moisture content	= 440 kg dry matter
Loss of volatiles during decomposition	45 kg
	= 395 kg dry matter in compost
Assume an extraction efficiency of 90% for the 120 kgs of other wastes	= 12 kg contraries and slavage in compost
	= 407 kg dry compost
Assume 25% moisture content of compost at time of sale	136 kg water
Compost produced/ton waste	= *543 kg. say 50% of intake.*

* in terms of essential and acceptable constituents

CHAPTER 16
PRINCIPLES AND ECONOMICS OF COMPOSTING

16.1 Principles of composting

A composting process seeks to harness the natural forces of decomposition to secure the conversion of organic wastes into organic manure. The purposes of controlling the process are:

— to make it aesthetically acceptable;
— to minimize the production of offensive odours;
— to avoid the propagation of insects or odours;
— to destroy pathogenic organisms present in the original wastes;
— to destroy weed seeds;
— to retain the maximum nutrient content, N,P, and K;
— to minimize the time required to complete the process;
— to minimize the land area required for the process.

16.1.1 Composting organisms There are two main groups of organisms which decompose organic matter:

— anaerobic bacteria, which perform their work in the absence of oxygen,
— aerobic bacteria, which require oxygen.

(There are also some facultative organisms that can adapt to either environment.)

Thus two alternative natural process are available as bases for composting plants. The main characteristics of anaerobic composting are:

— the process is a lengthy one extending over a period of 4–12 months;
— it is a low-temperature process and the destruction of pathogens is accomplished by their exposure to an unfavourable environment over a long period;
— the gaseous products of reduction are methane, hydrogen sulfide and other gases with offensive odours.

The main use of anaerobic composting has been in India, where for many years it has provided, usually on a small scale, a cheap solution to the combined disposal of solid wastes and nightsoil. These materials are placed

Indian wastes of the analysis given earlier probably fall within the optimum range of initial mositure content and are unlikely to require the addition of moisture during the first few days. During the thermophilic stage, however, the high temperature causes rapid loss of water and this must be replaced from time to time until the final fall in temperature. At this point it is desirable to allow the moisture content to decline to 25% in order to minimize the weight of material to be transported to the farm.

Should be moisture content accidentally exceed the maximum required level, for example, as a result of continuous heavy rain on exposed wastes, it is necessary to provide conditions under which the excess moisture will evaporate rapidly, and to aerate the wastes more frequently. This can be achieved by more frequent turning.

16.1.3 Sewage sludge as a source of moisture The initial mositure content of European wastes may be as low as 30% because of the high proportion of paper in relation to vegetable/putrescible wastes; thus the addition of moisture is necessary before composting can commence at full speed. For many years it has been a common practice to employ sewage sludge instead of water for the following reasons:

— the sludge is a source of additional nutrients, particularly nitrogen,
— the low C/N ratio of sludge, 6:1, helps to reduce the very high initial C/N ratio of European wastes, thus speeding up the process,
— this was an attractive solution to an otherwise difficult problem of disposing of sewage sludge.

The use of sewage sludge for this purpose is now being seriously questioned because of the possibility of transferring heavy metal toxicity to the compost, the source of these heavy metals being industrial effluents.

Even if it is certain that there is no risk of toxicity from sewage sludge, its use has disadvantages under the folowing conditions.

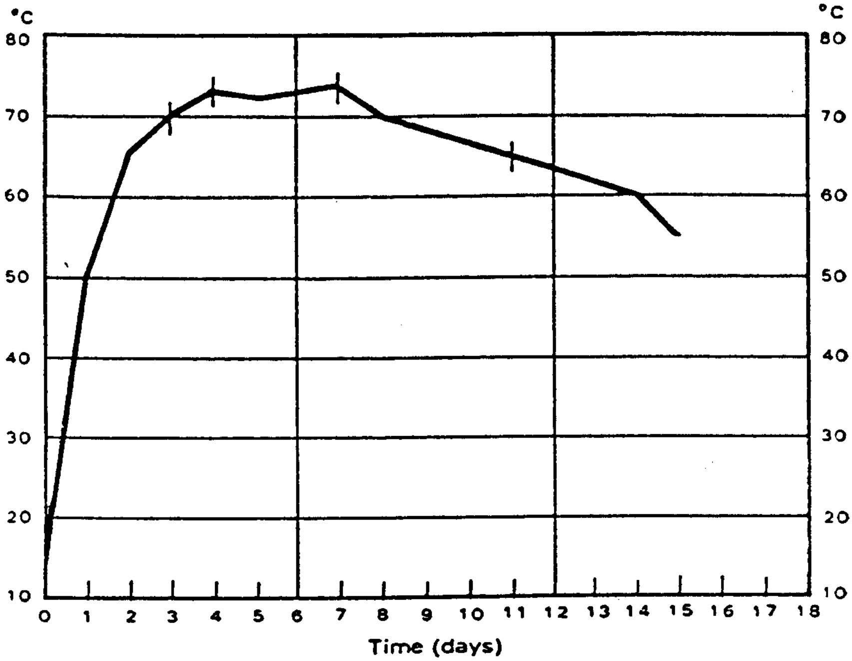
— when the initial C/N ratio is within the optimum range, because if the ratio is unduly depressed, there will be increased nitrogen loss during composting,
— when composting is carried out in the open air, because the sludge will give rise to offensive odours, and if raw, may cause health risks to workers.

In general, it would appear that the use of sludge in Indian composting is unlikely to confer any measurable advantage, and may give rise to some undesirable consequences.

16.1.4 Aeration Although a vast amount of research has been carried out to determine the quantity of air required by decomposing solid wastes, little of practical value has emerged. It has been demonstrated that oxygen demand is greatest at the beginning and declines as the process nears completion, and that an increase in moisture content imposes a need for more oxygen. But attempts to quantify oxygen requirements have

Figure 26

TYPICAL TEMPERATURE CURVE FOR A LARGE MASS OF AEROBICALLY COMPOSTING URBAN SOLID WASTES*



* Days on which pile was turned

From University of California studies

— After many months the centre of the heap will have been reduced to form of compost. It will be of very low value to a farmer, however, because it is adulterated by bottles, plastics, metals, stones and coarse fibrous materials, some of which may be large enough to interfere with cultivation; others will be dangerous to animals. The outer layers are likely to contain viable weed seeds and there is no certainty that pathogenic organisms have been eliminated.

(It is worth noting that this is precisely the process that occurs when a city disposes of its wastes by uncontrolled dumping!)

16.2.2 Minimum requirements for control From this it follows that the essential features of control are:

— the incorporation of coarse materials in the windrows increases the amount of interstitial air;
— both capital cost and energy consumption are greatly reduced by avoiding the size reduction process,
— the removal of contraries after decomposition is cheaper because decomposition reduces the volume of material to be handled by about one third, and the size of plant required is proportionately smaller,
— separation of contraries when the compost has a low moisture content after decomposition is much more efficient than with raw wastes with a high moisture content,
— the contraries, and any salvage that may be recovered at this stage, are free of pathogens and present no problems in disposal.

(b) *Windrowing of size-reduced wastes.* This is the most common type of plant in use today and has the following main features:

— Reception and storage; this can take the form of a deep bunker with a grab crane, or a hopper with slat conveyor;
— Elevation to attain sufficient height to enable subsequent process to be fed by gravity; e.g., by an inclined elevator belt, but sometimes the hopper slat conveyor is inclined and extended outside the hopper;
— Picking belt for the removal of salvage and contraries;
— Overband magnet, for the extraction of ferrous metal;
— Size reduction, normally a hammermill;
— Transport of the shredded wastes to the windrows; this can be by overhead conveyor belts or tractors and trailers;
— Windrow turning system; usually front-end loaders are used, but other machines are available;
— Storage area.

The heart of this type of plant, and the main justification for its added cost, is the hammermill, which reduces the size of the wastes to about 80% below 50 mm. This increases the surface area exposed to bacterial attack and may assist in speeding up the process of decomposition. It also mixes the wastes, destroys most of the fly larvae, reduces the attraction of the wastes to insects, and grinds glass to the equivalent of sand.

Shredding is certainly an essential treatment for the wastes of temperate, industrialized countries, for such wastes contain many objects which would be highly resistant to decomposition, but it may be a questionable requirement in countries where the proportion of vegetable/putrescible matter is very high, and where lower living standards and intensive private salvaging tend to minimize the proportions of salvageable materials and contraries in the wastes.

(c) *Windrowing of partly fermented wastes.* This type of system has all the features of the preceding type, except that instead of a hammermill a very large rotating drum is employed; this has a capacity of several hundred tons and the wastes are retained within it for up to 7 days during which the following functions are performed:

equivalent hygienic standard. The following is a convenient way of setting out a summary of the cost of composting. (The figures used are for example only and have no specific significance.)

Expenditure/income	*Rs/ton of wastes received*
Compost plant operating costs including amortization	50
Disposal of contraries (20% of input × Rs 10.00/ton)	2
Transport of compost (50% of input × 20 km × Rs 0.70/ton/km)	7
Total cost of operation	59
Income:	
Sale of salvage (2% of input × average value of Rs 250/ton)	5
Sale of compost (50% of input × Rs 50/ton)	25
Total income	30
Net disposal cost of wastes	Rs 29/ton

In this hypothetical situation, if the only alternative to composting was incineration at a net cost of Rs 150/ton, then composting would be the obvious choice, given adequate assurance on marketing. If, however, sites were available at which sanitary landfill to high standards could be operated at Rs 10/ton, composting would impose an unnecessary financial burden upon the city, however great its attractions may be from the agricultural standpoint.

16.3.2 Size of a city In an earlier section, the importance of securing a market for all compost was stressed. At the farm, compost must be applied in very large quantities; thus transport between the compost plant and the farm is an important cost element; in most situation this cost limits the marketing range to about 25 km. If the potential marketing area for compost is a circle of 25 km diameter and if the plant is in a very large city, much of that circle will be occupied by urban areas; therefore, the larger the city the smaller the potential market for compost. The larger the city, however, the greater the quantity of wastes. Thus composting as a policy suffers the paradox that the potential market is in inverse ratio to potential wastes production.

The consequence is that no major city has ever been able to base its waste disposal policy entirely on composing. The most successful composting plants have been those which serve small towns in agricultural areas and the widest application of composting in the past has been in the form of simple manual methods in villages.

16.3.3 Wage levels Wage rates have a profound effect on two aspects of compost plants:

— the viability of salvage extraction,
— the selection of mechanical or manual handling methods.

The history of the industralized countries shows that wage rates steadily increase, mainly because of rising productivity and partly by inflation; the market values of salvaged materials, however, rise at a much slower rate and sometimes do not rise at all. For example, in the United Kingdom before World War II many municipalities operated salvage plants for the recovery of paper, metals, bottles, textiles, rubber and cinder, and the income from the sale of these materials exceeded the cost of providing conveyor belts, electromagnets, and baling presses, as well as the labour cost of extracting, sorting and packing the salvage. Thus, at that time salvaging on a partly mechanized scale helped to reduce total disposal costs. This is no longer the case, however, because wage levels have risen much faster than salvage values: 1976 wages are probably 15 times pre-war levels, but the selling price of paper has increased only 5 times and the price of glass is unchanged: for most cities in the United Kingdom, salvage is no longer profitable.

For every community the viability of salvage extraction at any given time is a function of wage rates and salvage values; these may change significantly over the life of a plant which is normally about 20 years.

On the question of mechanical v. manual methods of operation, the choice is limited to certain specific work areas. Some level of capital investment is unavcidable: land, paving, and drainage, for example. Some process are practicable only by mechanical means: pulverization and ballistic separation in particular. On the other hand, there are certain processes for which manual methods may be superior or even essential; for example; the sorting of non-ferrous metals. But there are some work areas in which the amount of mechanization has to be decided in the light of current and forecast wage levels, plant and energy costs, and comparative performances. Windrows can be turned manually or by front-end loaders. If it is known that one man can turn 5 tons/day and a front-end loader of a certain size 120 tons/day, the comparative costs of 24 men against 1 loader provide the information on which the decision can be made. In making such comparisons allowance is always necessary for the cost of standby equipment required during plant maintenance as well as for labour oncosts arising from welfare facilities and fringe benefits.

16.3.4 Energy It is important to recognize that there may be constraints on energy consumption of two kinds:

— rising energy costs,
— uncertainty of continuous supply.

In a high-energy-cost area it may be possible to modify plant design to minimize energy consumption. Hammermills of 10 tons/hour capacity require at least 150 h.p., and up to 350 h.p. for 20 tons/hour capacity, when used for the treatment of raw wastes. However, if hammermills or rasps are used only as a final treatment after decomposition, power requirement is greatly reduced as a result of the structural changes which occur in the wastes during decompostion. Rasping after decomposition was a feature of the V.A.M. process which was used in Holland for many years. If the decomposed wastes are first screened, and only the oversize material passed through a hammermill, the energy requirement may be reduced to 20% or less of that needed for fresh unscreened wastes.

When a large capital investment is made in a composting plant it is vital to ensure that the public power supply is 99% reliable. Cases have been known where seasonal power cuts occur for long periods and this can be intolerable if the compost plant provides the only means of refuse disposal for a city. In some circumstances diesel engines may offer a more reliable energy source.

16.3.5 Indigenous equipment Mechanized refuse disposal methods were first developed in the industrialized countries and these are still the main suppliers of equipment, particularly items of patented design. Composting plants erected in developing or partly industrialized countries are usually of foreign manufacture and this can involve risks to long-term reliable operation through dependence upon imported spare parts, and may add to maintenance costs if heavy items have to be transported to great distances.

It is recommended, therefore, that a plant should be designed in the country in which it is to be erected and that the design should be based as far as possible on indigenous equipment. Where patents are involved, the possibility should be explored of local manufacture under licence. This applies with special force to items which are rapidly consumed, such as hammers for hammermills, or which are subject to sudden damage and require immediate replacement, such as conveyor belts.

CHAPTER 17
ELEMENTS OF COMPOST PLANTS

17.1 Storage and elevation

Storage of wastes has to be related to pre-treatment and collection to provide a continuous flow required for the efficient operation of a compost plant.

17.1.1 Storage capacity Whenever wastes are subjected to pre-treatment before entering the decomposition process it is necessary to provide a storage facility to convert batch deliveries of wastes into the continuous flow required for efficient operation of the plant. The storage capacity needed depends primarily upon the relationship between the hours of operation of the collection service and those of the compost plant.

The simplest pattern is when both services operate during a single daily shift and when working hours coincide; in this case storage capacity is decided by the working cycle of the collection vehicles. Unless staggered starting times are used, the whole collection fleet tends to arrive over a short period which occurs two, three or more times a day according to the average number of loads collected per vehicle/day. If the time interval between the arrival of successive waves of vehicles is, say, two hours, this represents the minimum storage capacity required to contain the wastes delivered by one wave of vehicles; alternatively, it represents the minimum store of wastes which will keep the plant in continuous operation. Some allowance is necessary, however, for other factors such as higher delivery rates after public holidays, and temporary plant stoppages. In practice no plant should have less than 4 hours storage capacity; for a plant of 20 tons/hour the storage volume should be equivalent to 80 tons. For wastes of a density of 330 kg/m^3 this would be about 240 m^3.

At the other extreme is the plant which operates continuously, three shifts per day for seven days a week, while the collection service works only a single shift for five or six days a week. In this situation, if allowance is made for public holidays, storage capacity may have to be equivalent to three or even four days' throughput: for a plant of 20 tons/hour capacity this could be as much as 2 000 tons. The attraction of such highly intensive plant operation is the reduction of unit operating cost by spreading the capital cost over the maximum throughput. For this reason continuous operation is now normal practice for large incinerators, especially when heat recuperation is practised. Compost plants, however, rarely operate over more than two shifts for six days a week, and it is seldom necessary to provide more than 10 hours storage capacity.

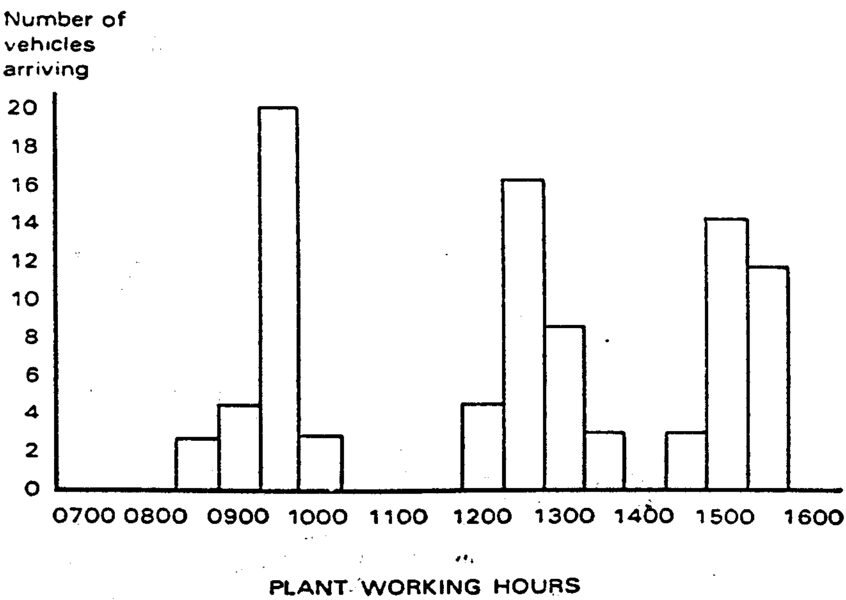
The vehicles in which the wastes are delivered discharge their loads from ground level by gravity. Therefore, unless an elevated road is provided, or a split-level site is available, the storage method must be combined with an elevating facility; this permits the use of gravity transfer between subsequent elements of the treatment process. Storage-elevation systems are of three main kinds, the choice depending on required capacity and cost:

— a deep concrete bunker with overhead grab-crane,
— a large steel hopper containing a steel slat conveyor feeding an elevator belt,
— direct dumping on a concrete floor from which the wastes are pushed by a bulldozer into an elevator.

One factor common to all these methods is the need to provide adequate reception space for vehicles at the discharge point.

Figure 27

TYPICAL PATTERN OF VEHICLE ARRIVALS AT A TREATMENT PLANT



17.1.2 Reception capacity This can be defined as the necessary provision for the simultaneous discharge of a number of vehicles. First, it is necessary to ascertain the average pattern of vehicle arrivals from time records. This will reveal the peak delivery period. If, for example, this is 20 vehicles over a period of 30 minutes, and if the average time required for a vehicle to enter the reception area, manoeuvre, discharge its load, and leave, is five minutes, then 100 vehicle-minutes must be accommodated within that 30 minutes period, equivalent to four vehicles discharging simultaneously.

Thus, one dimension of the storage capacity is determined by the required reception capacity, and in the case quoted above the minimum length of the bunker or the steel hopper would need to be sufficient to allow four vehicles to stand side by side with reasonable space between them. The width of the apron fronting the bunker or hopper is determined by the turning circles of the vehicles in use, or likely to be used in future, and should permit them to drive in and reverse for discharge without complex and time-wasting manoeuvring.

It will be apparent that the time during which a vehicle occupies a discharging space is critical to this aspect of plant design, and that all vehicles should be equipped with hydraulic tipping gear; no hand-unloading of vehicles should be permitted normally.

17.1.3 Deep bunkers Deep concrete bunkers are usually used only when the required storage capacity exceeds four hours of operation. The walls are vertical in order to allow the grab to work close to the sides, and sometimes incorporate steel protective strips to minimize damage from swinging grab. The side along which the vehicles discharge has a strong kerb or "bumper bar" to serve as a stop for the rear wheels. The width of the bunker must be great enough to accommodate that part of the vehicle which overhangs the bunker during unloading, plus the width required for operation of the grab. The total usable width, however, is limited by the fact that solid wastes have no natural angle of repose and tend to heap on the vehicle discharge side.

The capacity of the grab crane is determined by the volume of the grab and the average time cycle. The operator of the grab can be located in a cabin on the crane or in a control room which gives a total view of the bunker from above as well as a good view of the grab discharge point. Working conditions for the operator are better in a control room. Grabs may be of either clamshell or tulip pattern. A spare grab should be located in a position which enables a quick exchange to be made when repairs are needed.

Handling by grab is a batch process which cannot be used for direct transfer to a conveyor belt. A grab usually discharges into a surge hopper which can take the form of a plate conveyor or a vibrating feeder; these can provide a smooth feed to a conveyor belt.

The bunker and its equipment are enclosed by a building and the side at which vehicles unload is divided into apertures of convenient size which can be closed by swing doors when not in use. An alternative method of closure, or partial closure, and one which is less subject to accidental damage, is a suspended rubber curtain, formed from strips about 30 cm wide, which is merely pushed aside as the vehicle reverses into position.

The provision of dust extraction is possible by placing vents in the wall of the bunker opposite the vehicle unloading points, withdrawing the dust-laden air by means of a fan, and passing it through an air-cleaning plant, but the energy requirement is very high. A solution that satisfies most situations is the provision of atomized water sprays in the upper part of the building; water consumption is very small, but the water supply must be well filtered.

A disadvantage of this storage method is that the grab is unable to remove the wastes in the order in which they arrive; it takes the newest wastes from the top of the mass and old wastes tend to remain at the bottom where they putrefy. It is usually necessary to empty the bunker completely at least once weekly, and this involves lowering men to the bottom to clean out corners, loosen adhering matter, sweep up and hose down. It is useful to provide a sump in the base of the bunker into which washing water can drain, and a portable pump for emptying the sump.

17.1.4 Hoppers and slat conveyors When the required storage capacity is equivalent to four hours or less, it is usually possible to provide it in the form of one or more rectangular steel hoppers, two metres or more in depth, mounted over steel slat conveyors. Such conveyors, which are usually between two and three metres wide, are of simple and robust construction comprising a heavy continuous chain on each side, driven by sprockets. Each chain link carried a steel slat interlocked with its neighbours. The non-driven sprockets are adjustable for chain wear.

The range of capacity normally provided in this way is from 50 m^3 to 200 m^3. The required speed of such a conveyor is very slow: for example, a cross sectional area of two square metres discharged at a conveyor speed of 1 metre/minute equals a volume of 120 m^3/hour, or 40 tons/hour at a density of 330 kgs/m^3. It is usually necessary to provide an adjustable choke beam to control the rate of discharge; these sometimes cause blockages.

Horizontal slat conveyors normally feed a rubber/canvas elevator belt the inclination of which should not exceed 25°, and which usually runs at a speed of 20 – 30 metres/minute. The belt should be mounted on trough-idlers with sealed bearings. The volume to be handled per minute, divided by the belt speed, gives the average cross-sectional area of the load to be carried, e.g., 2 m^3 divided by a speed of 20 metres = 0.10 m^2. This could be carried on a belt one metre wide at an average depth of 100 mm.

Conveyor belts for solid wastes should be to a high specification, preferably neoprene/nylon. For troughed belts the nylon canvas should be of stepped ply construction to aid flexibility. Driving drums should be crowned 5 mm/metre of width to assist the true running of the belt.

When conveyor belts leave buildings and travel in the open air, they should be covered to prevent loss of wastes in high winds, but he covers should be accessible from a walkway and readily detachable.

17.1.5 Ground storage This method of storage requires a concrete floor of adequate size, preferably within a building, on which vehicles dump their loads. Adjacent to this storage area there is a small hopper from the base of which an inclined slat conveyor operates. This type of slat conveyor is usually less than 1 metre wide, has cleated slats to minimize slip, and travels between high, tapered, steel sides, at somewhat higher speeds than slat conveyors used in storage hoppers. Inclined slat conveyors have very little storage capacity and are continuously fed by a bulldozer, usually on a rubber-tired tractor.

Although aesthetically less attractive, this method is often the least costly in capital expenditure, and provides a very flexible storage arrangement. The operating cost of a bulldozer, however, may be greater than that of the electric motors, about 10 h.p., required to run a storage slat conveyor and rubber elevator.

17.2 Salvage

Solid wastes contain considerable amounts of material which could b sold after cleaning or treatment and some paper, textiles, glass and plasti can be recycled.

17.2.1 Picking belts The saleable materials in urban solid wastes a usually paper, textiles, glass, non-ferrous metals, and ferrous metal. A except the last have to be extracted by hand. Hand-sorting also permits t extraction of some contrary materials; it is a good thing to remove heav pieces of masonry or metal which could cause damage during some later treatment process. Plastics can be hand-picked if there is a sale for them otherwise it is easier to remove them by screening at a later stage.

The work of hand-sorting is not a pleasant occupation and the bes possible conditions should be provided for the workers. Usually th picking belt will be the first process after elevation and will be placed in the upper part of the building; it should be shut off from other processes by partitions to minimize dust and noise, and it should be well lit and ventilated. For dry wastes with a high dust-content it will be necessary to provide dust extraction hoods over the picking belt.

The speed of the belt should not exceed 15 metres/minute and its width should be not more than one metre unless it is to be worked from both sides. It should be flat, not troughed, and spillage should be prevented by retaining boards of wood or metal along both sides. Its height above floor level should be the average elbow height of the workers.

Chutes should be provided for the main categories of materials to be extracted. They should be adjacent to the belt, and must be on the same side as the workers. These chutes should lead to a room on the ground floor where the salvaged materials can be prepared for sale. Chutes are n suitable for bottles that will be sold intact, and it will be necessary to provide boxes for these. Boxes can also be used for materials which arise in very small quantities, such as non-ferrous metals.

Salvage pickers should be supplied with gloves to protect their hands from cuts and infection, and with face-masks if dust cannot be controlled by other means.

17.2.2 Magnetic extraction Electro-magnets are used for the extraction of ferrous metals when the quantity present in the wastes justifies such an installation. They require direct current, usually supplied by means of a rectifier. There are two common methods of magnetic extraction:

—magnetic head pulley,
—overband magnet.

The top (driving) pulley of an elevator belt can be fitted with internal magnets which cause light ferrous objects to cling to the belt during the period when other wastes are falling into the short chute which links the elevator to the next stage, usually the picking belt. As the ferrous metal is carried away, clinging to the underside of the belt, it passes outside the influence of the magnetic field and falls from the belt. A chute located at this point transfers the metal to a baling press on the ground floor. Magnetic head pulleys are not recommended for the following reasons:

—extraction efficiency is low, usually under 60%,
— small objects such as nails are pulled over the edge of the belt and cling to the drum itself, ultimately causing serious damage to the conveyor belt.

An overband magnet is a separate unit, usually located about 500 mm above a picking belt and at right-angles to it. It is a very short rubber conveyor belt. Magnets are installed between the top and the return sides of the belt and attract light ferrous objects from the wastes passing beneath. Most of this metal is in the form of tin cans; they cling to the underside of the rubber belt and are carried away, across the direction of travel of the picking belt, until they are outside the magnetic field, when they fall into a chute. There is a tendency for round objects to be retained within the magnetic field by rolling backwards while clinging to the belt; this problem is largely overcome by fitting rubber cleats to the belt.
The effective extraction rate is about 80% at best; it depends on the thickness of the wastes on the picking belt, and the height of the overhand magnet over the picking belt; this is adjustable. If maximum extraction rate is sought, there will be a significant proportion of other wastes carried over with the metal and this will have to be removed by hand before sale. If clean metal is required this can be achieved by reducing field strength, but the extraction rate will fall to 60% or less. To achieve a high extraction rate of clean metal it is usually necessary to employ two overband magnets in series.

17.2.3 Salvage treatment The chutes from the salvage extraction room will deliver the salvaged materials to the ground floor where they will be subjected to some further sorting and packaged for sale. The extent of this work will depend upon local conditions, particularly whether the materials are sold to a scrap merchant who will perform the final sorting, or direct to a factory for which they are the raw material. The following are the kinds of treatment that may be necessary:

(a) Paper. Paper which is to go to a paper mill for repulping usually has to be sorted into several grades, e.g., newspaper, fibreboard cartons, books and magazines, and mixed paper, each grade being used for a different product. Paper can be sold packed in sacks, but where large quantities are produced baling will be necessary. Baling machines range from simple hand-operated ratchet balers, which produce bales weighing about 100 kg, to large continuous reciprocating presses suitable to high rates of feed and which produce bales of 500 kg or more.

(b) Ferrous metals. There are many grades of ferrous metal, the main categories being thin sheet steel, heavy machinery scrap and cast iron. The main ferrous constituent of solid wastes is tin cans and other hollow articles; these need to be baled if they are to be transported to a steel works. The chute from an overband magnet can be arranged to provide direct feed to a hydraulic two-way metal press. The press operator should have access for the extraction of any contrary matter which contaminates the metal.

Complete recovery of the constituents of tin cans is practicable: the solder can be recovered by heat treatment and the tin by electrolytic baths, leaving the pure steel for re-melting. Factories which operate this kind of process usually prefer to receive the tin cans loose, not baled.

(c) Non-ferrous metals. The sorting and cleaning of non-ferrous metals is a skilled manual operation. The common metals are rolled aluminium, cast aluminium, copper, brass, zinc, and lead, but in many cases they are in the form of household articles which contain more than one metal and often some non-metallic constituents. For example, a kettle may be made from rolled aluminium and have a cast aluminium handle, which must be separated, and the kettle may contain mineral adhesions which need to be removed by beating it. A brass lampholder contains porcelain insulators which have to be removed; copper cable must be separated from rubber or plastic insulation, usually by burning off.

Cleaned non-ferrous metals are extremely valuable and good security is essential while they are being stored awaiting sale.

(d) Textiles. There are numerous potential uses for salvaged textiles. Woollen garments can be recycled into a lower grade of usage; they make excellent blankets. At the other end of the scale, carpet and gunny have been used to make bituminous roofing felt. Other uses include paper making and machinery wipers. It is usually possible to sell textiles mixed to a rag merchant who will carry out the sorting. They should be disposed of quickly; if left in heaps, or in bags or bales, they tend to heat up and decompose and their value is lost or reduced.

Salvaged textiles now contain a high proportion of man-made textiles and this has reduced their value in comparison with the time when they comprised mainly wool and cotton.

(e) Bottles. For bottles of a standard type there is often a wide market for re-use. For proprietary bottles, the only potential purchaser is the original producer, but he may be prepared to buy them back if they have been carefully sorted and washed.

Bottles extracted from solid wastes are usually sold to bottle merchants who perform this function.

(f) Broken glass. Unsaleable bottles can be added to the broken glass which must be carefully sorted into grades: clear, amber and green, and must be free of contraries such as metal tops.

A proportion of broken glass is used in the manufacture of all new bottles; some broken glass is used by the abrasives industry in the manufacture of glass-paper.

(g) Plastics. In some areas there is a market for salvaged plastics; usually plastic film is the easiest to dispose of. Processes are now being developed for the manufacture of various products, such as building boards, in which recycled mixed plastics are used as a bonding material. Thus the market for plastics of most kinds may expand in future.

17.2.4 Health aspects of salvaging Where salvage has been carried out under controlled conditions in plants designed for the purpose, there has been no evidence of adverse effects on the health of the sorters. There could, however, be risks to public health if the subsequent use of the salvaged materials is not carefully controlled. The main areas of risk concern paper, textiles, bottles and plastic film.

- — Paper must always be sold for re-pulping, in which it undergoes heat treatment. It must never be sold for direct reuse, as sometimes happens in the case of cartons and newspaper which can be used for wrapping food.
- — Salvaged textiles must never be used as fillings for mattresses and furniture.
- — During the salvage process any bottles that appear to have been used for secondary purpose, such as containers for kerosene, should be broken. At the bottle factory the cleansing process must provide effective sterilization.
- — Plastic film should be sold only for melting and recycling and never for re-use as wrappers.

This is a complex area of control which requires legislation on manufacturing standards for certain products and enforcement by health inspectors, together with vigilance and control by the solid waste management authority in the disposal of such materials. The best policy would be to sell paper only to re-pulping mills, plastics only to plastics manufacturers or extruders, and bottles and textiles to reputable merchants whose methods are open to inspection.

17.3 Size reduction

Size reduction is an advantage when a high proportion of the compostable wastes exceeds about 50 mm in size. It is particularly necessary when the paper content, after salvage, still includes cartons and thick publications, and when much of the vegetable content is in the form of large fibrous leaves and rinds. All size-reduction processes confer a secondary benefit by mixing the wastes into a more homogeneous material. Five methods of size reduction will be considered:

— hammermills,
— rasps,
— short-term drums,
— long-term drums,
— shears and cutters.

17.3.1 Hammermills A hammermill is a strong steel casing in which is mounted a rotating shaft, with a speed of several hundred revolutions/minute, which carries one or more rows of swing hammers. Wastes are fed into the top opening of the machine and are reduced in size by being struck repeatedly by the hammers. Some mills have a grid at the base for the retention of resistant matter until it has been sufficiently reduced in size.

There are two main types of hammermill, vertical shaft and horizontal shaft, and both are widely used. Vertical shaft machines tend to be lower in cost because they are of simpler design; they are effective because the wastes pass through successive rows of hammers with reducing clearances, thus avoiding the need for a grid. The horizontal shaft machines tend to employ heavier hammers and, because of their large rectangular feed openings, are favoured for "consumer society" wastes containing large items such as furniture.

The capacity range for hammermills used for solid wastes is from about 10 to 40 tons/hour and motor sizes range from 120 to over 400 h.p. All hammermills are provided with an arrangement which permits them to reject an intractable object. This may take the form of a spring loaded section of the casing which would yield and trap a heavy object. A more common arrangement is to provide an opening through which dense or resilient objects are projected by centrifugal force. The path of projection is vertical for a horizontal machine and horizontal for a vertical shaft mill.

The main cause of blockage in a hammermill is textiles, usually a bundle of sacks or a piece of carpet, but this problem is unlikely to arise if the mill is preceded by a picking belt.

Explosions have occurred in hammermills and one known cause is butane containers; this too, is an unlikely contingency and can be guarded against in two ways:

— vigilance by the pickers, and
— a casing design that permits the controlled absorption of explosive energy, for example by arranging for a heavy upper segment of the casing to be only lightly attached, but fitted with chain restraints.

It is not possible to avoid a hammermill becoming overloaded from time

time and it is usual to fit an electrical overload device which will halt in proper sequence the train of handling elements which supply it.

For the reduction of urban wastes a hammermill has limited efficiency; a common level of performance would be 85% below about 50 mm, and efficiency declines as the hammers become worn. For complete size reduction it would be necessary to provide two-stage milling and screening, but it is rare to find this type of installation today. Thus it is usually necessary to accept that shredded wastes will contain oversize matter; this is often in the form of plastics, rubber and textiles and implies a need for screening at some later stage of treatment.

The main operating costs of a hammermill are energy and hammer wear. (Paper is thought to be the main cause of hammer wear.) Hammers are of two main kinds: shaped steel castings the working faces of which are rebuilt daily or less frequently, by welding; and rectangular hammers cut from standard sizes of steel bar. The second type costs less and is expendable after having been reversed end-to-end and top-to-bottom, thus utilizing four cutting edges. The life of this kind of hammer can be extended if it is originally tipped with hard weld-metal. A local source of replacement hammers is important if expenditure is to be kept to the minimum.

17.3.2. Rasps Size reduction in a hammermill is achieved by heavy blows from a high-speed hammer; a rasp operates on a similar principle to a perforated vegetable grater used in the kitchen. The wastes are shredded by being pushed under pressure across hard protrusions between which are perforations which allow size-reduced particles to pass.

The Dorr-Oliver rasp comprises a cylinder more than five metres in diameter which is divided into an upper and lower chamber. Wastes are delivered by conveyor to the upper section, which is the rasping chamber and the floor of which is formed by segmented perforated plates between which are fitted unperforated sections on which cast manganese pins are mounted for abrasive purposes. A central shaft carries 8 rotating rasping arms which force the wastes across the manganese pins. The arms are pivoted to permit them to ride over an intractable object.

Wastes which have been sufficiently reduced to size fall through the perforations (which can be from 25 mm upward in diameter according to requirements) to the lower collecting chamber. Here the central shaft carries four sweeping arms which push the wastes to a discharge opening below which is a conveyor.

Wastes which resist size reduction accumulate in the rasping chamber from which they are removed from time to time through an opening and chute.

A machine of this type has a capacity of 10–12 tons/hour of raw refuse and the installed power is 2×40 h.p. motors. When used for the treatment of wastes that have already been decomposed in windrows, the capacity may be much greater than this because a high proportion of the crude compost will be small enough to pass straight through the machine while the strength of the oversize fibrous matter will have been reduced by partial decomposition.

The rasp was used for the V.A.M. process in Holland and has the following advantages:

- positive size reduction, thus screening is not necessary except for grading purposes,
- energy consumption and maintenance frequency are less than those for a hammermill.

17.3.3 Short-term drums An alternative to the hammermill or rasp is to tumble the wastes in a revolving drum for between one and two hours. For this to be effective in achieving size reduction the initial moisture content must exceed about 50% in order to reduce the strength of the paper in the wastes; if necessary, water is added to the wastes as they enter the drum. Excessive moisture content, however, may result in the formation of large balls of wastes.

One type of drum consists of two concentric cylinders. The inner one, into which the wastes are fed, is perforated, so that as the wastes are reduced in size they pass into the space between the two cylinders. The inner cylinder is fitted with baffles to assist agitation of the contents.

The wastes are discharged in two streams: size-reduced screenings and oversize rejects. However, size reduction is less effective than a hammermill, and therefore the proportion of rejects may be quite high and may contain a proportion of desirable compostable material. The appearance of the screened material is good; despite the short retention time, it loses most of the visible characteristics of fresh wastes. Although such drums have a much lower energy requirement than a hammermill, they have not achieved popularity, probably because their low throughput, usually about 5 tons/hour, limits their application to small-scale projects.

17.3.4 Long-term drums Judged by the number of plants built and operated successfully, this has been one of the most notable composting systems of the post-war period. After a salvaging stage the wastes enter a long steel cylinder, resembling a cement kiln, which has a capacity of up to 300 tons and is rotated at speeds from two to seven revolutions/minute. At the point of entry the wastes are brought up to the required moisture level, if necessary, by the addition of water or sewage sludge. Air is supplied to the interior and the CO_2 and other gaseous products are vented. At some of the earlier plants these gases were found to cause offensive odours in the vicinity and it is now customary to exhaust them through trunking to an underground filter of sand, gravel and sometimes charcoal.

The drum is slightly inclined to the horizontal and the wastes slowly pass along its length. Initially the retention period was about 5 days and most drums had a daily capacity of about 50 tons. Tests under these conditions always confirmed the destruction of pathogens.

The drum is a costly feature, however, and at many plants the contents are retained for only three days in order to achieve a greater throughput for a given level of capital expenditure. At one recently erected plant the retention period is only two days and a further reduction of this period is being contemplated in the hope of attaining a throughput approaching 200 tons/day. Under such conditions it is important to recognize that:

- there is no certainty of the destruction of pathogens, insects and weed seeds during this phase,
- physical reduction is less and the proportion of oversize contrary matter is greater,
- decomposition has only just begun when the wastes are discharged; thus the retention period in windrows and the number of turns for aeration will be similar to the requirement for shredded or crude wastes.

The interior of the drum is fitted with wear plates. Maintenance is not a frequent need as with a hammermill, and occurs only at long intervals during which the plant must be shut down while re-lining is carried out.

Whatever the retention period in the drum, the material emerging contains contrary materials such as broken glass, plastics, textiles and stones. Thus further treatment is required before or after windrowing. This normally includes screening and ballistic separation, and treatment by hammermill is sometimes provided.

17.3.5 Shears and cutters The methods of size reduction which have been considered so far are normally applied to 100% of wastes input, less salvage extracted, the justification for this being the physical character of the wastes, in terms of constituents and size, as established by analysis. There are some situations, however, in which size reduction is necessary only for certain specific wastes which form a small percentage of the total. For example:

- if it is desired to add straw, or similar material in order to increase the C/N ratio,
- if it is desired to return to the windrows the undecomposed fibrous vegetable matter which is usually screened out of wastes which have been composted in their crude state.

It may be necessary to chop such wastes to facilitate mixing and decomposition, and a simple machine may be adequate for such a purpose. The chaff-cutter, with rotary blades turned by hand or a small motor, is an effective tool of low cost. A rapid reciprocating shear operating over a flat bed is another alternative; the blade, on which a heavy weight should be mounted, can be operated by a pair of cams.

17.4 Windrow layout and management

The windrowing stage is the most important part of every composting system except for those rare plants in which a digestor is employed. The area occupied by the windrows should be paved, drained, and provided with a water supply. The capital cost of this is proportionate to its area, which should, therefore, be kept to a minimum by careful design of layout and operation. The other main cost element is that of turning the windrows to aerate them, and the choice of method to perform this work requires equal care.

For all systems except that of static aeration, described later, it has been found that the optimum height for a windrow is between 1.6 and 2.0 metres. The reasons for this are:

— at lower heights the temperatures achieved are less,
— at greater heights anaerobic pockets are more likely and manual trimming is difficult.

Width is less critical: 1.5 to 2.0 metres width has worked well in small operations; 3.0 to 4.0 metres are normal, and it is possible that greater width would be acceptable if conditions so required. The length of a windrow has no effect on its biological operation, but the most convenient length is usually that which contains one day's production, in order to simplify the turning rota.

The main aspects of plant design for the windrowing phase are:

—transfer of wastes to windrows,
—aeration of windrows,
—layout of windrows.

17.4.1 Transfer to windrow by conveyor The use of a conveyor system to carry the wastes from the treatment plant and distribute them in windrows is low in operating cost and fairly reliable. It is necessary for the conveyor to be able to discharge continuously at any point along its length. This is achieved by passing the conveyor belt through a movable tripper carriage. The tripper is fitted with a short transverse belt on to which the main conveyor discharges. The transverse belt discharges at the side of the main belt, and, if necessary, is reversible, so that continuous windrows can be formed on both sides.

Tripping conveyors employed are of two types: fixed and radial. A fixed conveyor is not very practical; it can form only two windrows, one on each side. As the space between the windrows is occupied by the supporting structure of the conveyor system, the windrows are accessible only from the outside and turning is extremely difficult. This method is used normally only with static aeration systems which avoid turning.

The supporting structure of a radial conveyor is mounted on rails. The tripper is fixed at a given point while the conveyor system travels slowly round its axis and in this way windrows are formed in concentric arcs. Each arc can be a continuous windrow provided that markers are inserted to indicate the date of deposit. Such windrows tend to be triangular in section, and thus occupy more ground for a given volume than those formed by some other methods. It may be that this is why designers of such systems usually make the error of creating windrows of excessive height; this reduces the capital cost of the system but can lead to anaerobic problems.

In both fixed and radial systems the height of the windrow can be controlled by a probe suspended near the discharge point. When the wastes reach a sufficient height to move the probe, either the tripper carriage or the radial carriage is moved forward by electrical contact.

In both systems the retention time of the windrows is fixed and at the end of that time the compost is removed to a storage area, or a post-treatment plant, so that new wastes can enter the cycle.

17.4.2 Transfer to windrow by tractor The most common method of transfer is by tractor and trailer. It is the more flexible system, and very reliable, for while the failure of a conveyor system would stop the plant completely, a plant is unlikely to employ only one tractor. It is more costly in operation, however, because three handling elements are involved:

—loading a trailer,
—transport and unloading the trailer,
—stacking unloaded wastes in windrow.

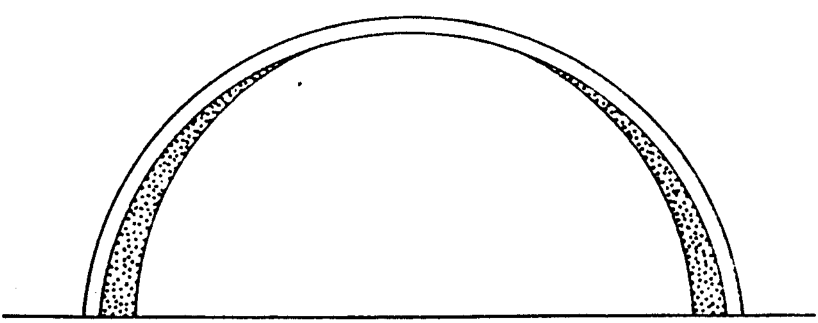
The first of these can be avoided if the treated wastes are discharged by gravity directly into a trailer. However, if discharge is at ground level, as has frequently been observed, a front-end loader is required to fill the trailer.

Stacking wastes in the windrow incurs the cost of a front-end loader or manual labour, but the shape of the windrow can be made to economize ground space by forming it with a gently rounded top instead of the conical shape which results from conveyor discharge.

17.4.3 Direct delivery to windrows Where the character of wastes makes it possible to windrow them without prior treatment, a significant cost advantage is achieved because delivery to the windrow is made in the collection vehicle. But these vehicles arrive in waves and it is necessary to

Figure 28

WINDROW AREA INHABITED BY FLY LARVAE



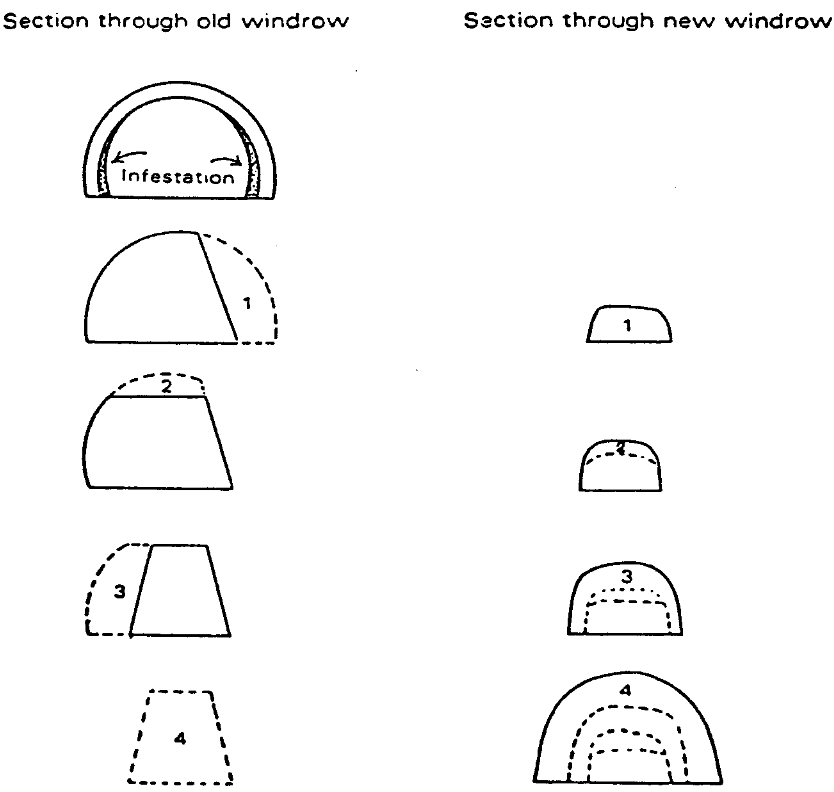
Dark area is that inhabited by fly larvae on the fifth day
(adapted from WHO Monograph No. 31, "Composting", Gotaas)

make provision for peak periods. Layout should permit, therefore, of delivery to both ends of a windrow which is under formation, and in this way it may be possible to discharge four vehicles simultaneously. These peak periods will tend to interfere with the work of the front-end loader which is engaged on windrow building.

17.4.4 Windrow turning There is a positive relationship between the frequency of turning and the speed of decomposition. Under the most perfect conditions, in a digestor, the period may be as short as 7 days, but it is unlikely to exceed 20 days in a windrow which is turned about 4 times and is unlikely to be less than 14 days in a windrow turned daily. Turning is a costly process and should not be employed unnecessarily. For wastes of optimum C/N ratio, in warm or temperate climates, it has been found that three turns over a 20-day period (the fourth turn being removal to a

Figure 29

WINDROW TURNING PROCEDURE



post-treatment plant, or to a storage area) are sufficient. The method of turning, however, is of very great importance for the elimination of pathogens, insect larvae and weed seeds. This requires that the original outer layer should always form the centre of the new windrow after turning.

The area inhabited by fly larvae is shown in Figure 28. The required turning procedure to transfer the infested portion of the wastes is shown in Figure 29.

Turning and re-forming a windrow requires adjacent space:

—for a front-end loader, or men, to work,
—for formation of the new windrow.

This space can be provided in two ways:

— as an extension of windrow length, to provide for longitudinal turning, or
—vacant space at the side of the windrow, for transverse turning.

Longitudinal turning requires less ground space and for manual operation the transfer distance is minimized. It is not practicable for a front-end loader, however, and if mechanized turning is required, it is necessary to employ a shovel in which the bucket is loaded at the front after which the loaded bucket passes over the machine from front to back and discharges at the rear. Accurate placing of the material, as is required for insect control, is difficult with such a machine. There is also the problem that during most of the turning procedure the machine is locked between the old and the new parts of the windrow, and in the event of breakdown it would be difficult to move it.

Transverse turning manually is possible if the space between the old and the new windrow site is kept to a minimum, say one metre, but transfer of the far side of the old windrow to the centre of the new one may require double handling owing to the distance. The procedure with a front-end loader is straightforward, but requires that the whole windrow is turned end-to-end (see Figure 30). Thus it is desirable to keep the length of a windrow to the minimum and this is one case when the width of the windrows should be allowed to exceed the customary four metres.

Tools used for manual turning include a drag (a kind of fork with four tines at right-angles to a long, two-metre handle); a pitchfork; shovel and broom for tidying up.

The best shape for a windrow is probably an approximate semi-circular cross-section. This makes the best use of ground space, is easy to form, and sheds the rain.

17.4.5 Windrow layout The number of windrow spaces required will be based upon the retention period; if each windrow is to contain one day's wastes and the retention period is 15 days, at least 15 spaces, usually more, will be needed.

The size of a windrow space is determined by daily volume and the cross-sectional area of the windrow. For example:

For an input of 100 tons/day at a density of	400 kg/m³
the total daily volume would be	250 m³
For a windrow width of 4 metres and an average cross section of 6 m², the length of a windrow would be	42 m
+safety margin of 20% =	50 m

The total space required will comprise:

—basic windrow spaces,
—spaces between windrows,
—road access along all sides of windrow site,
—additional windrow length if turning is longitudinal,
—additional windrow spaces if turning is transverse.

For the above example the required windrow area would be as follows:

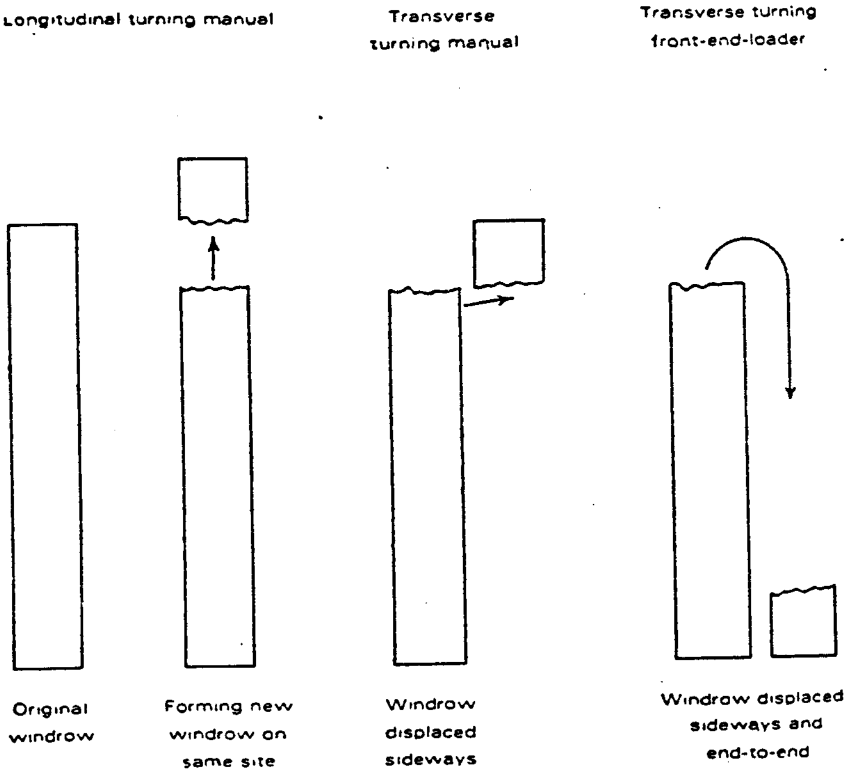
(a)	Longitudinal turning:	
	Basic windrow length	50 metres
	Allow for turning	5
	10-metre road at each end	20
		= 75
	Windrow width	4
	Space between	1
		= 5
	× 15 windrows	75
	+ 5-metre road at each end	10
		= 85
	Site required: 85 m × 75 m = 6 375 square metres equivalent to 64 square metres/ton/day	
(b)	Transverse turning:	
	Basic windrow length	50
	10-metre road at each end	20
		= 70
	Windrow width	4
	Space between	1
		= 5
	× 19 (15 windrow + 4 spare for turning in rotation)	95
	+ 5-metre road at each end	10
		= 105
	Site required: 70 m × 105 m = 7 350 square metres equivalent to 74 square metres/ton/day.	

To these areas it would be necessary to add space for the other treatment phases: reception, plant, storage, as well as for administration and maintenance facilities.

Rectangular sites usually occupy the minimum space, but two circular layouts are also possible. One is the system of concentric windrows formed by a radial conveyor, which has already been described.

Figure 30

WINDROW LAYOUT



The second is the use of radial windrows round a central treatment plant. The most likely application of this arrangement would be when crude, not treated, wastes are windrowed, after which they must pass through a plant for the removal of contraries. The radial arrangement permits the use of portable conveyors which can be placed by the side of a windrow, and loaded manually, for transfer of the compost to the plant. The portable conveyors would feed a portable elevator pivoted at the point where it discharges into the plant. The whole conveyor and elevator system would be moved each day from one windrow to the next. In areas of low labour cost this method of transfer is likely to be cheaper to operate than the usual system of trailers loaded by a front-end loader and towed by tractors.

17.4.6 Water supply to windrows During the turning of windrows by hand or machine, the addition of water is usually necessary. For this purpose an underground water main should be laid through the windrow area and hose connection points provided at convenient intervals. These points should be below ground level and covered by metal flaps when not in use, to avoid damage by vehicles or plant.

The whole of the windrow area should be drained so that surplus water, or leachate from windrows after heavy rain, can be collected. This liquid, which may be rich in nutrients, should not be discharged to the main drainage system but collected in tanks so that it can be pumped back to the windrows as an alternative to the use of fresh water.

17.4.7 Static aeration of windrows Because of the high cost of turning, whether manual or mechanized, systems have been devised which seek to eliminate the need for turning by forcing air through a windrow. A typical arrangement is to provide large air jets at ground level, at intervals of a few metres, along the length of each windrow space. The jets are supplied with air under pressure, by a system of underground pipes. Shredded wastes are deposited on these windrow spaces, by either a fixed or radical conveyor system, to a height of about four metres, about double the normal windrow height. Advocates of the system claim that the increased height is made possible because of the large volume of air which passes through the windrow from the jets at the base. The retention period is 18–21 days.

Some problems have been encountered with this system. The most obvious ones are:

—tracking of the air supply through the less dense areas of the wastes,
—anaerobic pockets,
—rapid loss of moisture and the drying-out of some areas,
—no decomposition of wastes at the outer surface.

Attempts to replace lost moisture by overhead sprinkling have not generally been successful as most of the water runs down the sides of the triangular windrow and fails to penetrate the mass.

Some plants have been built in which the air is drawn through the windrow from outside and exhausted through the jets in the base, through a ground filter, by means of an exhaust pump. Theoretically this should assist in moisture control, if atomized sprinklers are in use, by drawing moisture-laden air through the windrow. In practice, however, a black liquid of high BOD, collected in the suction system, causes corrosion and damage to most of the components.

17.4.8 Compost-turning machines The front-end loader, which is normally employed for the mechanized turning of windrows, is not ideal for this purpose. Much of its operating time is spent in manoeuvring in a limited space: positioning for attack at the correct point in the old windrow, reversing away, then travelling forward to the correct place to empty the bucket in forming the new windrow. Some final manual trimming is usually necessary. The ideal would be a machine which could travel continuously through a windrow, reforming it in a manner which would displace the original contents so as to achieve insect control, and perhaps add water at the same time.

A machine of this kind is being developed in India. It comprises a bridge at a height of 2.5 metres, supported by vertical columns, carried on four pneumatic tyres, at each end. Suspended from the bridge are four augers, contra-rotating in pairs, which penetrate the windrows to within 50 mm of ground level. The machine spans a windrow and travels very slowly throughout its length; the rotating augers transfer matter from the base to the outside of the windrow at all levels, and have overhead sprinklers for adding moisture. It is driven by electric motors through a variable speed gearbox, and is connected to the supply by means of a wander-lead. This machine is mobile, requires no fixed overhead structure or rails, and can be steered by the operator. It is possible that the operating cost for windrow turning could be less than that for front-end loaders. The latter would still be required, in reduced numbers, for windrow formation and removal. As this type of machine turns the wastes in situ, the need for spare windrow spaces for sideways turning would be avoided.

17.5 Screening

There are only two processes which are absolutely essential for the successful composting of wastes of every kind; decomposition is the first and screening the second. To be readily saleable the compost must have a maximum particle size; it cannot command a good price if it contains sheet plastics, old boots and coconut shells. For general agricultural use the screened size is likely to be in the range of 25 mm to 40 mm. Fragments of inert matter such as stones, plastics and man-made textiles which are below this size are unlikely to interfere with cultivation, or to mar the other qualities of the compost. Screening provides a total solution to the removal of contrary materials, within commercially practicable limits, except for fragments of glass; this problem will be considered later.

The size-reduction processes described earlier, such as hammermills and long-term drums, do not avoid the need for screening because both these methods pass a proportion of oversize materials, but rasps and short-term drums, which incorporate perforated plates, eliminate the need for screening other than for grading purposes.

17.5.1 When to screen Screening can be applied at one or more stages of treatment:

—before size reduction,
—after size reduction and before windrowing,
—after windrowing.

The usual purpose of screening before size reduction is to provide some measure of protection against oversize material to a hammermill. The type of screen used for this purpose could be vibrating bars spaced at about 100 mm. It is now customary to install hammermills of sufficient volume and power to avoid the need for this kind of protection.

At most compost plants screening is performed after the size reduction process and immediately before windrowing. The cost of installation is reduced when processes can be linked together, each feeding by gravity the one that succeeds it. However, the effectiveness of screening is inversely proportional to the moisture content; at this stage the wastes are likely to be high in moisture, either because they are fresh or are emerging from a drum. Thus screening at this stage usually results in a higher proportion of rejects which include some oversize compostable material and compostable matter which is carried over through being attached to contraries. Screened rejects produced at this stage present disposal problems as they contain insect eggs and larvae (unless they have been retained in a drum for an adequate period).

Although it requires the provision of a separate feeding and handling process, the screening of compost after windrowing has several advantages:

—efficient screening because of low moisture content,
—minimum proportion of rejects (or maximum compost production)
— the rejects are free of pathogens and insects, and can be disposed of without problems.

17.5.2 Rotary screens Rotary screens are the most efficient in extraction, and reliable in operation, for solid wastes. Their efficiency stems from a relatively long retention period during which the wastes are tumbled and separated from each other. There are two methods of transporting the material through a screen: by inclining the screen from the horizontal or by fitting it with an internal spiral.

The wastes occupy a cross-sectional area enclosed by a chord and part of the circumference; the capacity of the screen is a function of this area and the speed at which the wastes pass through the screen. A rotary screen is usually carried on rubber idlers and driven through a gear ring at one end. Small rotary screens may be mounted on a central shaft driven by a belt and pulley, but internal supports must be kept to a minimum as they soon collect rags and wire.

When installed in a building, the whole screen assembly should be contained within a steel casing to prevent dust dissemination.

Screen plates are detachable and renewable. A screen may be fitted with more than one size of mesh if it is required to produce two or more sizes of product, provided that separate chutes are fitted below each stage.

17.5.3 Vibrating screens A vibrating screen is in the form of a slightly inclined, perforated table across which the wastes are propelled by rapid vibration. Grading of the product can be achieved by placing tables in series. Because of lower capital cost and smaller space required, compared with rotary screens, it is now customary to use vibrating screens in compost plants.

They have the following disadvantages, however, for the treatment of both wastes and compost:

— blockage of apertures occurs much more rapidly than with a rotary screen,
— there is insufficient agitation to break up clumps of materials,
— constant attendence is needed by one or more men to clear blocked perforations and assist the passage of the materials across the screen.

By contrast the rotary screen needs no manual assistance, so the higher capital cost may be more than offset by a much lower operating cost.

17.6 Ballistic separation

Screening does not achieve the total removal of glass fragments; there are two ways of solving this problem:

— final grinding in a hammermill, which reduces glass to the equivalent of sand,
— ballistic separation, which also removes other dense particles such as small stones.

The principle of ballistic separation of dense particles is the projection of the compost at high speed; the trajectories of the particles will vary according to their densities, the path of the high density particles being much longer than that of those with low density, and this provides a basis for separating them mechanically.

There are at least two methods of applying this principle:

— to arrange for the compost to fall on to a rotating drum to which fins are attached; as the fins strike the particles differing velocities are imparted to them,
— to discharge the compost over the end of a very high speed conveyor belt.

The need to provide either of these facilities is dependent upon:

— the initial proportion of glass in the wastes,
— the efficiency of preceding extraction processes,
— the extent to which the glass may have been already ground by a preceding hammermill treatment,
— the relative importance to the farmer of the presence of glass fragments in the compost.

Ballistic separation is not of very high efficiency and, as with magnetic extraction of ferrous metals, it is necessary to compromise between maximum extraction with some loss of compost, and maximum compost production with some adulteration.

17.7 Storage area

The demand for compost is almost certain to be seasonal, and the storage area required is likely to be in the range of three months, to six months' production. (This fact makes meaningless the argument often put forward by manufacturers of expensive and sophisticated plant that their system reduces the area of land required by shortening the decomposition process by several days.) The storage area also serves a secondary purpose as a maturing stage. After transfer from the windrows or post-treatment plant, the compost is likely to have a final and limited rise in temperature before the slow decline to ambient commences. The process of transfer and stacking will entrain sufficient air for this phase.

It would not be economical to store such large quantities under cover, and in any case there is little risk of the loss of nutrients by leaching. During periods when heavy rain occurs the compost should be stored in triangular windrows so that the rain is shed; compost has some self-thatching characteristics which help it to resist water penetration. In dry areas there is no special requirement for stacking, and continuous flat heaps provide the best use of ground space.

17.8 Weighbridge

Except in the case of very small plants the provision of a weighbridge is recommended for the following reasons:

19. Pilot project for manual composting at Bangalore. Input is about three tons/day and the processing time up to 20 days.

Each windrow holds about three tons and is turned by hand at least twice.

— the input of wastes can be measured,
— the weight of all plant product—salvage, rejects and compost—will be known,
— plant efficiency can, therefore, be monitored with accuracy,
— it is seldom practicable to sell salvaged materials other than by weight,
— it is desirable to sell compost by weight owing to the difficulty in calculating volume in vehicles of varying types.

The size of a weighbridge, in terms of platform length and weight pacity, should allow for possible future increases in the sizes of vehicles use.

When a weighbridge is to be used for sales, there is a risk of fraud by nployees; various recording devices are available which help to reduce ich risks.

For large plants, say 300 tons/day upward, the weighbridge office iould be located on an island site with a platform on each side, to enable igoing and outgoing vehicles to be weighed without causing traffic roblems.

CHAPTER 18
OUTLINE DESIGNS OF TYPICAL SYSTEMS

18.1 Manual windrow compost plant

Manual windrow composting with post-fermentation treatment has three possible applications:

— as the wastes disposal method for a town of about 10 000 population, having a production of 300 g/person/day at a density of about 330 kg/m^3,
— as a pilot project for a larger city which is planning the construction of a compost plant,
— as a source of covering material for a landfill site serving a population of 20 000 or more.

18.1.1 Capacity The capacity is based on three tons wastes/day incoming and a daily compost production rate of $1^1/_2$ tons.

18.1.2 Method Refuse would be delivered direct to one of 20 windrow spaces on unpaved but level and well-drained land. Each day's wastes would be formed into a windrow about 3 m long x 2 m wide × 1.5 m high; the total volume in a windrow would be about 9 m^3.

Each windrow would be turned on the 6th and the 11th days, the outside to the centre, to destroy insect larvae and to provide aeration. On the 16th day the windrow would be broken down and passed through a manually operated rotary screen of about 25 mm square mesh to remove oversize contrary materials. The screened compost would be stored for about 30 days in a maturing heap about 2 m wide × 1.5 m high, and up to 20 m long to ensure that it was stabilized before sale.

18.1.3 Area required For such a plant, which produces compost at the rate of 1.5 tons a day, the area required would be:

20 windrow spaces, 3 m × 2 m, + 0.5 m space between	150 sq. m
Central roadway for delivery of wastes, 25 m × 4 m	100 sq. m
Maturing (storage area), 25 m × 2 m	50 sq. m
Entrance area 15 m × 4 m	60 sq. m
Total	360 sq. m
Say,	400 sq. m

18.1.4 Staff required The staff required for a manual windrows compost plant of the type described here would be :

Daily tasks:	1 windrow to be stacked from new wastes	9 m^3
	2 windrows to be turned (volume declines during decomposition)	15
	1 windrow to be broken down and screened	6
	Total	30 m^3

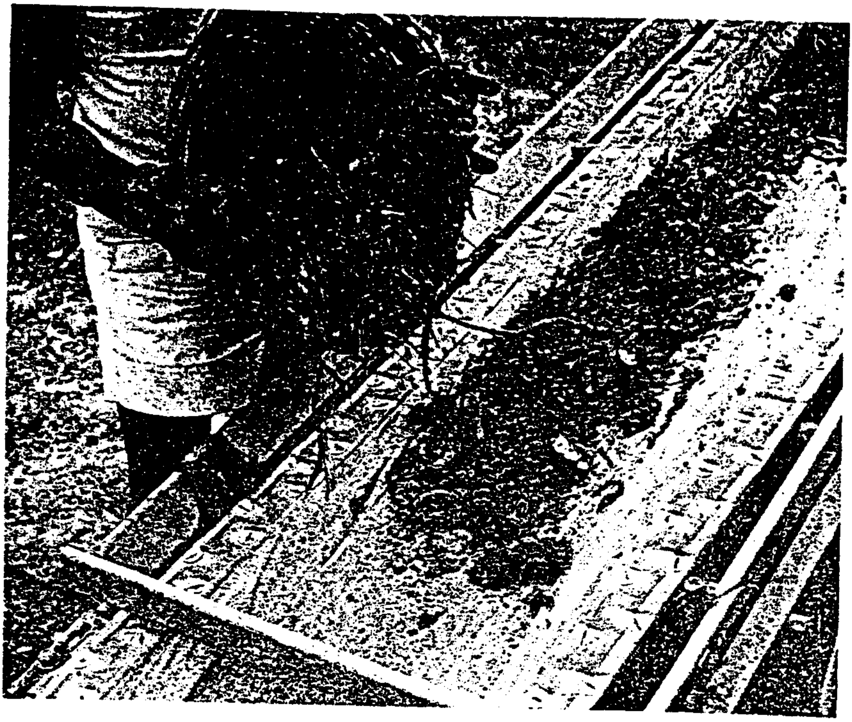
1 man can turn 5 tons (up to 15 m^3) a day; therefore 2 men would be required; plus 1–1$^1/_2$ men for screening, etc.

18.1.5 Rotary screen The rotary screen could be a simple, inclined, perforated drum, hand operated through a geared drive. The height at which it is mounted should be low enough to permit direct loading by hand (from a small platform if necessary). Discharge of the screened material could be to ground level, but it is preferable to provide a low hand-cart to receive the screened compost.

18.1.6 Cost Costing (1975 price level) of the plant could be calculated under the three heads—capital costs, operating costs and production costs:

Item	*Rs*
(a) Capital costs:	
Hand-operated screen	3 000
Fencing and gates, say, 80 m, 5 strands barbed wire, Rs 400, + Rs 400 posts and erection	800
Total (Rounded)	4 000
(b) Annual operating cost:	
Amortization, say 20% of capital	800
3$^1/_2$ men @ Rs 5/day = Rs 18/day	5 400
Tools and equipment	200
Boots and gloves	350
Disinfectant, etc.	50
Total	6 800
(c) Compost production cost:	
If 300 tons produced/year, cost/ton =	23
Add for supervision and administration	10
Total production cost	33/ton

The probable selling price is Rs 50/ton. Thus, at this scale of operation and assuming no cost for rental of land, income may exceed expenditure and refuse disposal cost would be nil. The unit costs and performance figures used here are based on the Hebbal Pilot Plant at Bangalore.



21. Crude compost being transferred to the elevator belt which feeds the rotary screen. At this stage some salvage is recovered.

windrow would be turned on the 6th and the 11th days and removed to the treatment plant on the 16th day. A planned turning sequence is very important, see Figures 31 and 32.

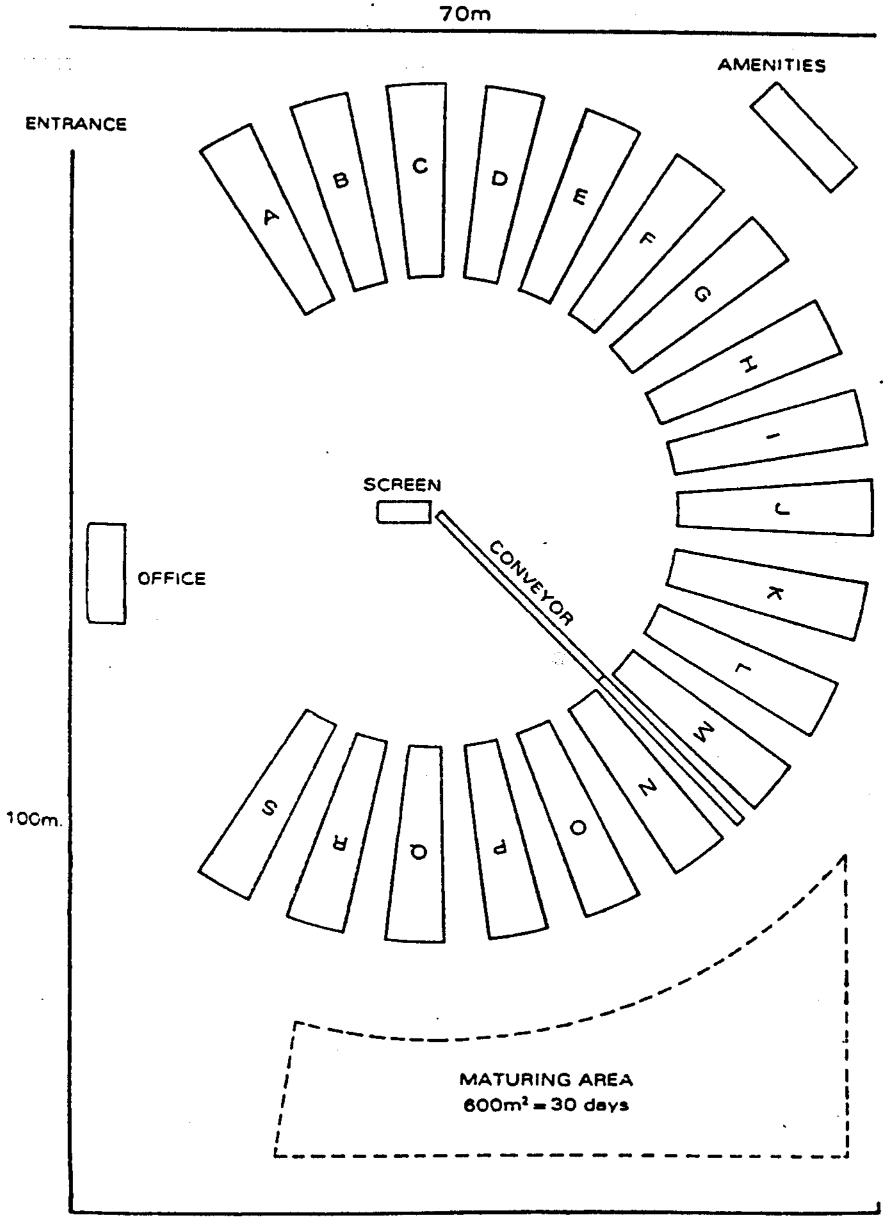
The average dimensions of a windrow would be 25 m long × 3 m wide on the inner radius and 5 m wide on the outer radius; average height 1.5 m. A space of about 1.5 m should be provided between windrows.

18.2.1 Radial windrow compost plant This design is based on the following characteristics:

— capacity 50 tons wastes/day at a density of 330 kg/m^3.
— product 25 tons compost/day, density 600 kg/m^3.,
— operation 8 hours/day, 300 days/year,
— windrow retention period 15 days,
— windrow layout radial to central post-treatment plant.

No plant precisely of this design has been built, but all the elements of which it is composed have been tested in practice.

Figure 31
LAYOUT OF RADIAL WINDROW PLANT



Site Area 0.7 Ha = 1.7 acres

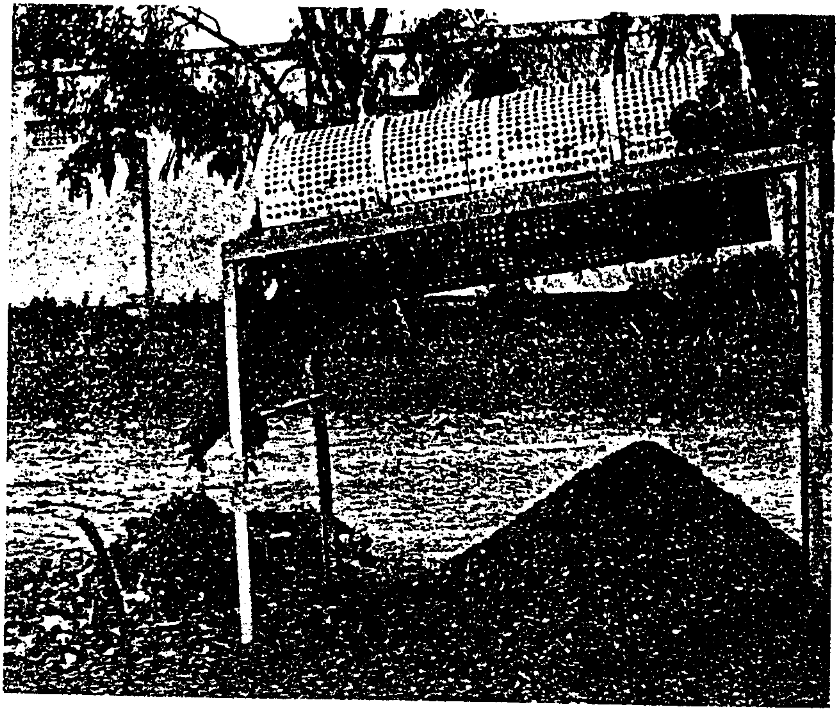
Figure 32

WINDROW TURNING SEQUENCE

This table should be read in conjunction with the preceding diagram which shows 19 spaces, A to S, of which 15 contain stacked windrows and 4 are spare for turning purposes. The first day's delivery of wastes is stacked in Windrow C, where it remains for five days, being transferred to Windrow B on Day 6. The second day's delivery is stacked in Windrow D, remains for five days and, on Day 7, is transferred to Windrow C, vacated the day before. By Day 17 the last Windrow, S, is stacked, and the third day's delivery has been restacked twice, has been five days in windrow C, and is ready for removal, making room for the 18th day's delivery, again into Windrow C, and so the process continues.

Windrow	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
Day 1			1																
2			1	2															
3			1	2	3														
4			1	2	3	4													
5			1	2	3	4	5												
6		1		2	3	4.	5	6											
7		1	2		3	4	5	6	7										
8		1	2	3		4	5	6	7	8									
9		1	2	3	4		5	6	7	8	9								
10		1	2	3	4	5		6	7	8	9	10							
11	1		2	3	4	5	6		7	8	9	10	11						
12	1	2		3	4	5	6	7		8	9	10	11	12					
13	1	2	3		4	5	6	7	8		9	10	11	12	13				
14	1	2	3	4		5	6	7	8	9		10	11	12	13	14			
15	1	2	3	4	5		6	7	8	9	10		11	12	13	14	15		
16		2	3	4	5	6		7	8	9	10	11		12	13	14	15	16	
17			3	4	5	6	7		8	9	10	11	12		13	14	15	16	17
18			18	4	5	6	7	8		9	10	11	12	13		14	15	16	17
19			18	19	5	6	7	8	9		10	11	12	13	14		15	16	17
20			18	19	20	6	7	8	9	10		11	12	13	14	15		16	17
21			18	19	20	21	7	8	9	10	11		12	13	14	15	16		17
22			18	19	20	21	22	8	9	10	11	12		13	14	15	16	17	
23		18		19	20	21	22	23	9	10	11	12	13		14	15	16	17	
24		18	19		20	21	22	23	24	10	11	12	13	14		15	16	17	
25		18	19	20		21	22	23	24	25	11	12	13	14	15		16	17	
26		18	19	20	21		22	23	24	25	26	12	13	14	15	16		17	
27		18	19	20	21	22		23	24	25	26	27	13	14	15	16	17		
28	18		19	20	21	22	23		24	25	26	27	28	14	15	16	17		
29	18	19		20	21	22	23	24		25	26	27	28	29	15	16	17		
30	18	19	20		21	22	23	24	25		26	27	28	29	30	16	17		
31	18	19	20	21		22	23	24	25	26		27	28	29	30	31	17		
32	18	19	20	21	22		23	24	25	26	27		28	29	30	31	32		
33		19	20	21	22	23		24	25	26	27	28		29	30	31	32	33	
34			20	21	22	23	24		25	26	27	28	29		30	31	32	33	34
35			35	21	22	23	24	25		26	27	28	29	30		31	32	33	34

NOTE : Underlining means removed to treatment plant.



22. After screening the compost is ready for transfer to the stockpile where it matures. The rejects must be disposed of in a landfill.

18.2.2 Volume to be handled in windrows daily The volume to be handled in windrows every day:

1 windrow to be stacked	150 m^3
2 windrows to be turned (volume declines)	250 m^3
daily total	400 m^3

With a manual performance of 15 m^3/man/day, up to 30 men would be required if no mechanical assistance was available.
A mechanical shovel with a 0.7 m^3 bucket, operating at 60 cycles/hour for 6 hours/day would have a daily capacity of 250 m^3.
For estimating purposes it is proposed to allow for 30 men as well as about 4 hours/day attendance by the mechanical shovel.

18.2.3 Transfer to treatment plant The daily task of feeding the treatment plant is the breaking down and transfer of one windrow, the volume of which will have been reduced to about 100 m^3 during decomposition. It is proposed to effect this transfer by means of one or more portable conveyor belts. About eight men would be required for loading the belts.

The capacity needed for the conveyor system is about 20 m^3/hour. A belt width of 300 mm at a speed of 20 m/minute would have a theoretical capacity of about 30 m^3/hour, thus providing a 50% margin for uneven loading. The total length required is 25 m.

This conveyor would discharge to a radial elevator, pivoted at the feed chute of the treatment plant. The length, width and speed would be similar to the preceding horizontal conveyor, but the height of discharge would be determined by the treatment plant, probably about 4 m.

18.2.4 Treatment plant This would comprise a rotary screen and a ballistic separator. The screen could be horizontal, about 4 m long × 1.2 m diameter with an internal spiral having a pitch of 1.5 m. At a speed of 10 r.p.m. the capacity would be about 20 m^3/hour.

The screen drum could be attached to, and enclosed within, an unperforated drum about 3.5 m long and 1.8 m diameter; this would contain screenings and facilitate their discharge to a ballistic separator.

The ballistic separator could take the form of a belt of 300 mm width travelling at high speed; a variable speed range of 200–400 m/minute is suggested.

18.2.5 Transport of products The ballistic separator would discharge refined compost direct to a trailer at a rate of 25 tons/day, say 5 tons/hour, or 8 m^3. This would be about 3 trailer-loads/hour and it would be necessary to exchange the trailer once every 20 minutes.

Screen rejects would also discharge directly to a second trailer at the rate of about 1 ton/hour; trailer exchange would not be necessary more frequently than once an hour.

Ballistic rejects would be discharged almost horizontally across the compost trailer and would fall at the foot of a safety screen. The daily quantity would be quite small, perhaps 2 m^3, and this could be removed from time to time in a wheelbarrow.

One tractor and three trailers would, therefore, have adequate capacity for internal transport of the treatment plant products.

18.2.6 Area If storage of the compost is needed only for the minimum maturing period of 30 days, the total site area would be about 0.7 ha. A site area of one ha. would allow sufficient storage space for at least 4 000 m^3 of compost, i.e., 100 days' production.

18.2.7 Summary of labour and mobile plant required A summary of labour and mobile plant required is given below:

Labour:	
stacking and turning windrows	30 men
removing windrows	8 men
plant operation	5
cleaners	5
mechanic	1
drivers	2
Total	60 including 9 spare men

Mobile plant:	
mechanical shovels; windrows, 4 hours/day, storage and loading for sale, 2 hours/day	1
tractors	1
trailers, 4 m^3 tippers	3

The operating cost (1975 price level) of this system is estimated to be about Rs 70/ton of compost produced. Details are provided in Chapter 19.

18.3 Post-treatment by rasp and screen

This windrow compost plant with post-treatment by rasp and screen, built at Bangalore by the Karnataka Compost Development Corporation, 1976/77, has the following characteristics:

- — input capacity 200 tons/day mixed wastes from markets and communal containers,
- — density as delivered 400 kg/m^3 = 500 m^3/day,
- — density after windrowing estimated to be 600 kg/m^3,
- — daily volume after windrowing and moisture loss, 250 m^3,
- — daily operating period, minimum 7 hours, maximum 10 hours.

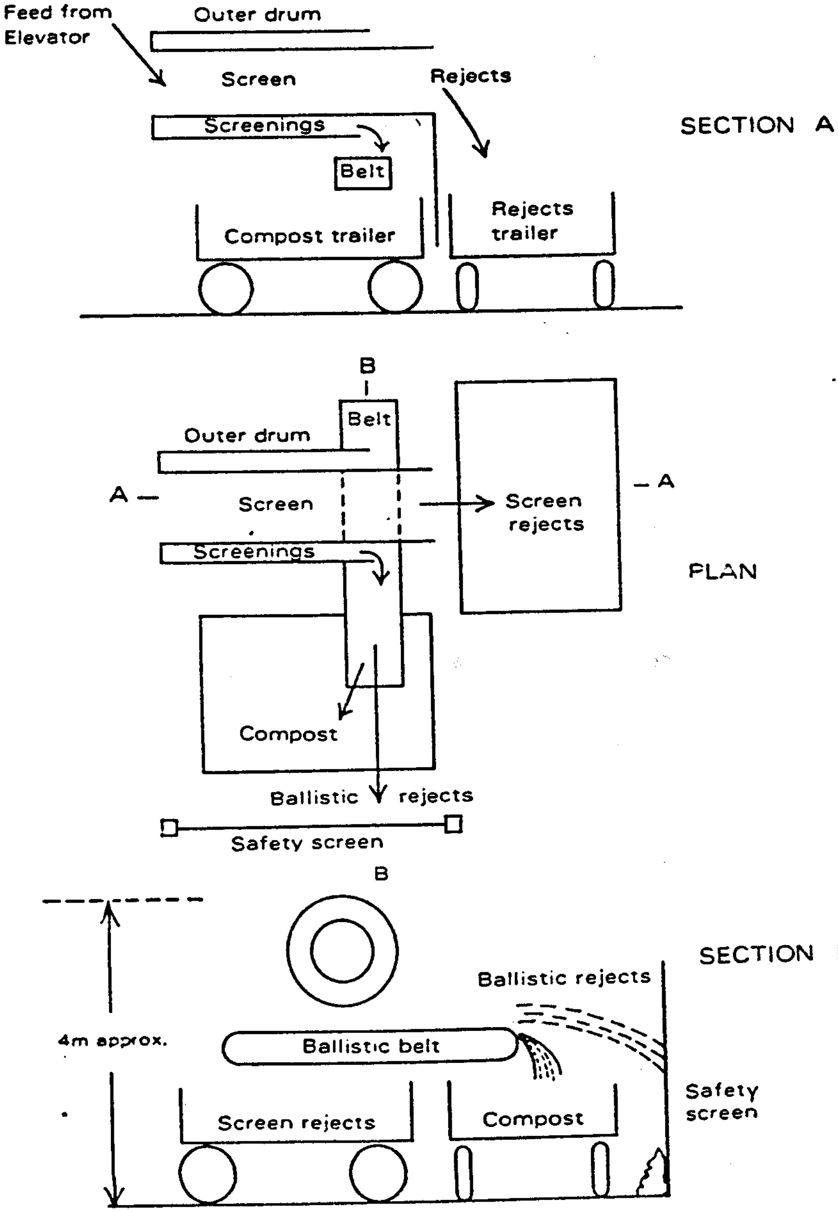
The plant provides for incoming wastes to be weighed after which they are delivered direct to the windrow site; thus the vehicles which deliver the wastes must have tipping gear. The crude wastes are formed into windrows by a front-end loader and will be turned three times during a retention period of 20 days. Turning may be done by a front-end loader or by an auger machine. On the 20th day the wastes are removed from the windrow by a front-end loader and transported by tractor-trailer to a treatment plant. This comprises a reception hopper with a slat conveyor which has an elevating section which delivers the crude compost to a salvage room. Here salvage and contrary materials are removed from a picking belt over which is mounted an overband magnet. The picking belt delivers to a rasp which shreds oversize matter and rejects intractable objects. The product of the rasp is delivered by a troughed elevating conveyor belt to the screen house, where the compost is graded for size according to market requirements. If screening is not required, the compost can be bypassed direct to a trailer at ground level. Screened products are also delivered direct to trailers which are exchanged at suitable intervals by tractors which deliver to the compost stockpile which also serves as a maturing area.

Design parameters are listed below:

Fermentation period	20 days in windrows.
Windrow arrangement	If turning by auger, 20 windrows, if by front-end loader, 23 windrows, to allow for rotation, each of 200 tons.

Figure 33

50 TONS/DAY TREATMENT PLANT



Windrow cross section	4 m. wide, each separated from the next one by 3 m. Wastes would be stacked to an average height of 2 m to provide an initial cross section of 8 sq m which would reduce during the fermentation process.
Windrow length	About 60 m providing an initial total windrow volume of about 500 m^3.
Total area for windrowing	20 (or 23) windrows. 60 m × 4 m = 2 400 m^2 20 (or 23) spaces 60 m × 3 m = 1 800 m^2 Space for vehicles to manoeuvre at each end of windrows: 150 m × 10 m wide × 2 nos. = 3 000 m^2 TOTAL 7 200 m^2
Turning programme	1st day : Stacking 5th day : Turn 10th day: Turn 15th day: Turn 20th day: Remove to treatment plant
Treatment plant	Weight/day 150 tons Volume/day 250 m^3 Hopper capacity 50 m^3 having a discharge side (for vehicles) at least 12 m long to permit two vehicles to discharge simultaneously. Slat conveyor to run full length of hopper and elevate to feed picking belt in salvage room. Slat conveyor 1 m wide with speed variation 2–4 m/minute. Picking belt speed 10 m/minute; chutes for transfer of salvage to ground-level containers; overband magnet. Rasp fed by picking belt, perforated plates available in 25 mm and 35 mm sizes. Rasp discharges to troughed conveyor belt which delivers to a separate screen building. The open air section of the conveyor will have a walkway and the belt will be protected by detachable covers.

	The screen will comprise three sections capable of grading from 10 mm upward; it will be totally enclosed to minimize dust but easy access will be provided for cleaning and maintenance. At the entrance to the screen will be a bifurcated chute to permit the screen to be bypassed. Trailers will be provided to receive materials from bypass chute and screen sections.
Plant products	Compost, maximum 120 tons/day. Rejects, by hand-sorting and rasp, up to 30 tons/day.
Storage area	Daily volume, say 200 m^3. Storage up to 150 days = 30 000 m^3. Storage pattern: continuous flat heap about 2 m high = 15 000 m^2 area.
Minimum land required	Entrance, weighbridge, administration and other buildings 0.20 ha Windrow area 0.72 Treatment plant, work-shops,plant, park, etc. 0.30 Roads 0.50 Storage 1.50 3.22 ha (Actual site area at Bangalore is 6 ha)

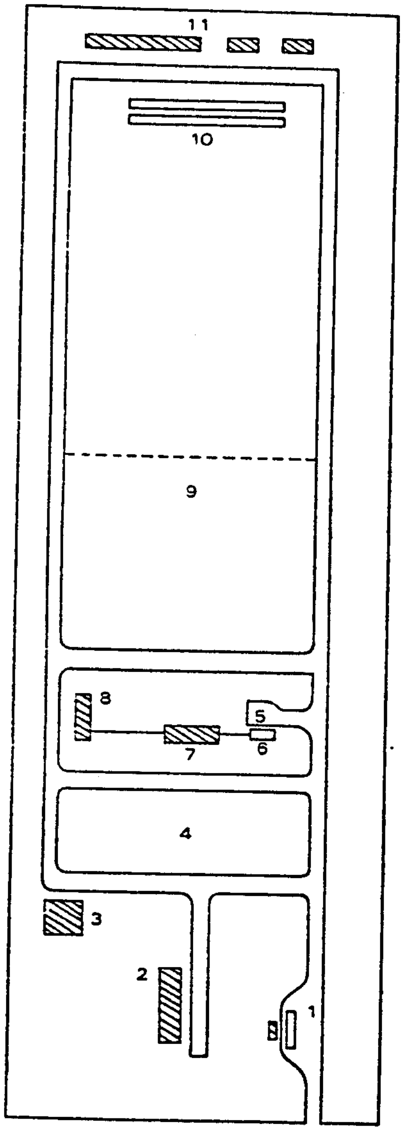
The logistics and cost estimates for this plant are dealt with in Chapter 19, in comparison with alternative methods.

NOTE: An interesting design aspect of this plant concerns the relationship between rasping and screening. The pilot tests showed that, after windrowing, the proportion of oversize compostable matter was not more than 10% by weight and about 20% by volume. It would have been possible, therefore, to eliminate the rasping process and to have used screening alone. In this case it would have been necessary to return compostable screen rejects to the windrows for a second composting cycle. The capital cost would have been reduced by about Rs 1 000 000. The argument in favour of the rasping stage is that it increases the weight of plant output for direct delivery to the maturing area and it separates intractable rejects such as bricks.

The decision to include the rasping process having been made, the question then arises as to whether screening is necessary. This is an issue which depends upon rasping performance. Known rasp performance with crude refuse is 10 – 12 tons/hour, only half of what is required at Bangalore. It is certain to be much higher with composted wastes, but the multiplying factor is unknown, and the problem will be solved by trial and error; 25 mm segments will be fitted initially and if these pass the wastes at the required rate, the product could go straight to the maturing area unless

Figure 34

POST-FERMENTATION PLANT 200 Tons/Day
Karnataka Compost Development Corporation, Bangalore



1. Weighbridge
2. Administration
3. Welfare
4. Reserve area
5. Ramp road to receiving hopper
6. Hopper
7. Salvage and Rasp building
8. Screen house
9. Compost storage area
10. Windrow area, 2 windrows are shown
11. Stores and maintenance buildings

Roads are 7m wide
The site has a bore well and a water storage tower

it is necessary to screen out a 10 mm horticultural grade of compost. If, however, it proves necessary to increase perforation size to achieve the necessary throughput, 25 mm screening will be necessary, and for this plant, the first of its type, the inclusion of the screen is prudent.

A final question is whether screening should take place before or after rasping. If the crude compost was screened first, the rasp would receive only oversize matter, the volume of which would be unlikely to exceed 25% of plant intake. In these circumstances the required capacity of the rasp would be greatly reduced and a smaller machine would suffice with a consequent reduction in capital cost and energy consumption.

18.4 Pre-treatment plant 400 tons/day

The plant has a capacity of 24 tons/hour divided between two independent lines and is representative of the type of compost plant which has been most popular since about 1960. It comprises bunker storage to facilitate multiple-shift operation, salvage recovery, size reduction by hammermills, screening, magnetic extraction, windrowing in the open and post-fermentation treatment.

Each numbered element is described below:

18.4.1 Plant elements

(1) Wastes are delivered in vehicles with hydraulic ejector plates.

(2) & (3) A weighbridge is provided at which all materials entering or leaving the plant are weighed and recorded.

(4) Because of the nature of the site, deep excavation for the storage bunker was not practicable and its base is at ground level. The necessary height for storage capacity has been achieved by building an inclined road up which the vehicles are driven to an unloading apron situated at the top.

(5) The tulip pattern grab has a clearance of 6.8 metres and a capacity of 1.5 cubic metres. It is controlled from a fixed cabin.

(6) The capacity of the bunker is 1 700 m^3 gross. Part of this capacity is not usable normally because the wastes form a heap on the open side of the bunker. If necessary, the grab could be used to move the wastes to the rear of the bunker which would then hold (at the current density of 280 kg/m^3) about 450 tons, but as normally operated the capacity is about 300 tons, say, 15 hours of operation.

(7) Wastes are transferred from the bunker to one of two elevators. These are steel plate conveyors (slat conveyors), inclined at an angle of 25°, and driven by variable speed motors in order that the rate of feed to the hammermills can be regulated.

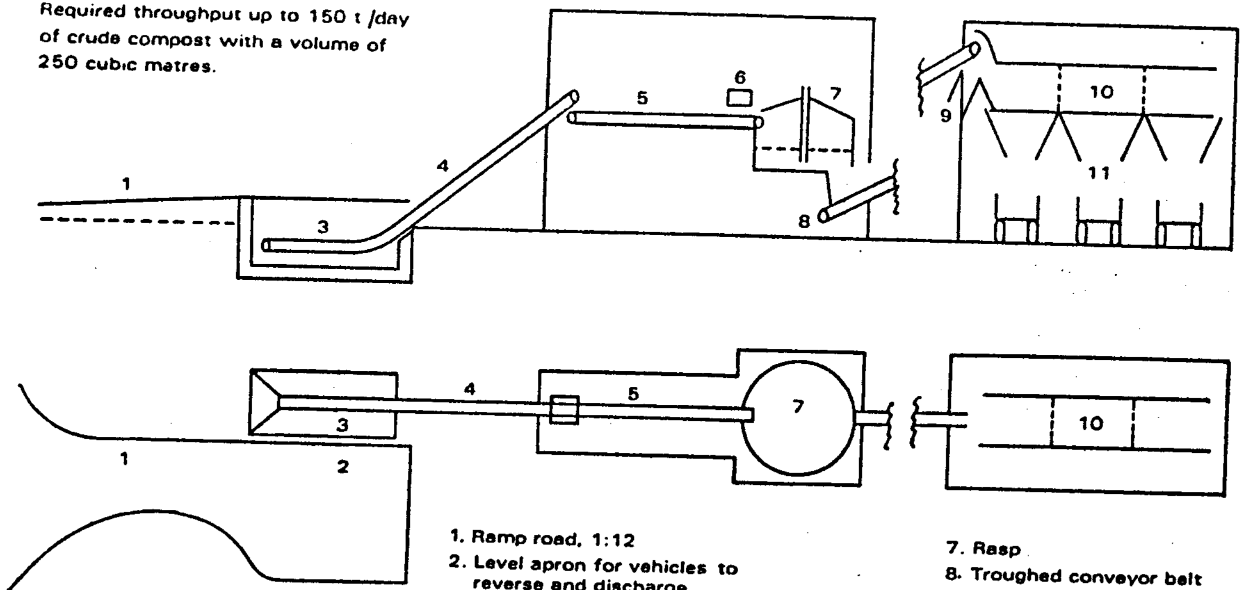
(8) Each elevator discharges directly to a picking belt with stations for 18 men, 8 of whom pick paper; 2, metal; 2, glass; 2, plastics; and the remainder deal with rejects or are mobile.

(9) Chutes are provided on both sides of the belts for products of the picking belt.

Figure 35

KARNATAKA POST-TREATMENT PLANT 200 Tons/Day

Required throughput up to 150 t /day of crude compost with a volume of 250 cubic metres.



1. Ramp road, 1:12
2. Level apron for vehicles to reverse and discharge
3. Reception hopper
4. Slat conveyor
5. Picking belt
6. Overband magnet
7. Rasp
8. Troughed conveyor belt
9. Bifurcated chute
10. Screen
11. Trailers to receive compost

(10) The chutes discharge to conveyor belts which transport each product to a container or trailer at ground level. Full trailers are taken to the appropriate area for further sorting, as in the case of textiles, or to a baling press as in the case of paper.

(11) The wastes which remain after hand-sorting are discharged to a feed chute leading to a hammermill.

(12) Each hammermill has a capacity of 12 tons/hour and is of the horizontal shaft type with expendable hammers. These can be turned and changed side to side to prolong their lives. Initially hammer life was 48 hours, equivalent to about 600 tons of wastes, but by the use of improved steel and heat treatment this has been extended considerably.

(13) As the pulverised wastes leave the hammermill they are transferred to a separate building by means of an enclosed chain conveyor.

(14) Ferrous metals are extracted first by a magnetic head pulley and later by an overband magnet.

(15) The vibrating screen is fitted with plates having circular perforations of 100 mm diameter. Other sizes could be used if necessary.

(16) Screen rejects are carried away by a conveyor belt.

(17) The treated wastes are conveyed by an elevator belt to the distribution system in the windrow area.

(18) Formation of the windrows, 25 metres long × 6 m wide × 3.5 m high, is performed automatically by a system of overhead conveyors on travelling carriages.

(19) After several days these windrows are removed by front-end loader to an adjacent area. This operation provides the first turn.

(20) When fermentation in the windrows is completed, the coarse compost, which still contains much oversize and contrary matter, receives post-fermentation treatment in a separate building; this comprises a hammermill and a vibrating screen the mesh of which is normally 20 mm.

18.4.2 Estimated costs In the following estimate, capital costs and labour and administrative staff numbers are factual. All other figures are the writer's estimates, based on the actual performance that may be expected over the total life of the project, expressed in average unit costs for India, 1975.

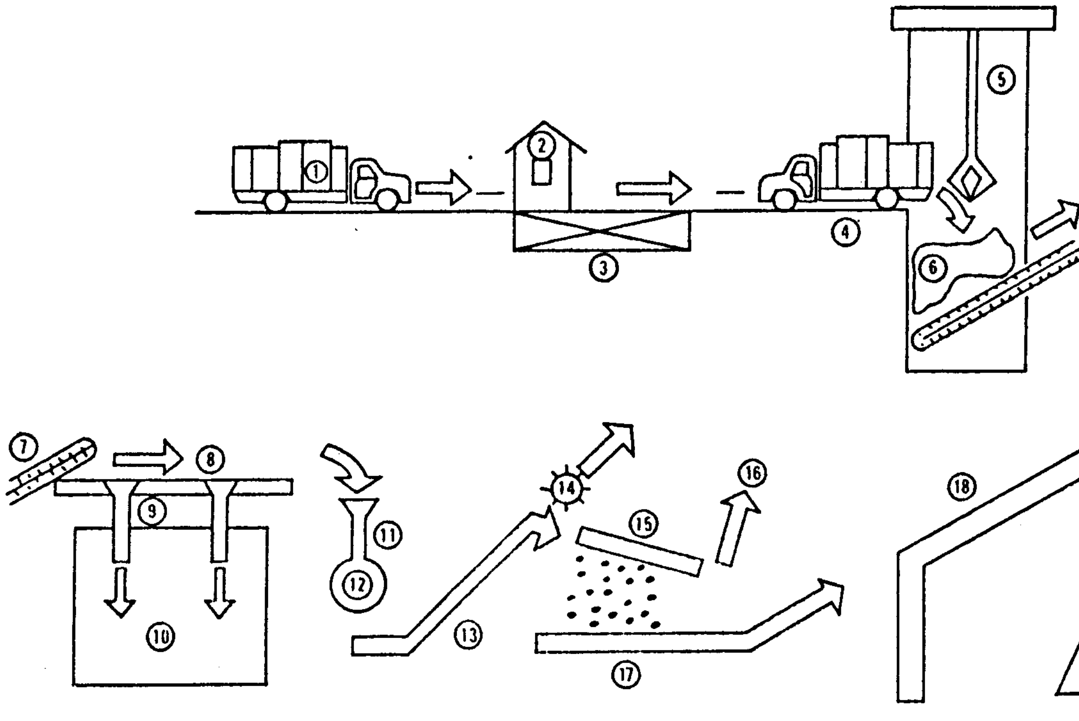
This plant is of particular interest in that it is operated over three shifts, effectively about 20 operating hours/day. This has the advantage of spreading fixed costs over a much greater tonnage, but to make it possible some extra capital cost had to be incurred in the form of bunker storage and increased windrow area. Labour costs and maintenance costs are, of course, proportional to the number of shifts worked, and mobile plant must be depreciated over a much shorter period compared with single-shift working.

The annual throughput is calculated on a three-shift basis for 5 days a week, less four hours/day for maintenance and shift changing:

2 lines × 10 tons/hour × 20 hours/day × 250 days/year = 100 000 tons of wastes entering the plant, compost production 50 000 tons/year.

Figure 36

PRE-TREATMENT PLANT, 400 Tons/Day
(Mexico Federal District)



Item	*Rupees*	
	Annual cost	*Cost/ton compost*
FIXED PLANT		
Capital cost actual at 1972 prices:		
Mechanical Rs 10 000 000		
Civil Rs 16 000 000		
= 26 000 000		
Depreciation, 15 years	1 730 000	
Interest 10% on outstanding loan, = average 5%	1 300 000	
	= 3 030 000	60.6
Mechanical repairs 3% × 3 shifts	900 000	
Civil repairs, 1%	160 000	
	= 1 060 000	21.2
Energy, Rs 2/ton wastes received	200 000	4.0
MOBILE PLANT		
Capital cost 2 000 000, life 3 years,	660 000	
Interest average 5%	100 000	
Maintenance, 33% (3 shifts)	660 000	
Fuel	60 000	
	= 1 480 000	29.6
LABOUR & ADMINISTRATION, 3 shifts		
205 men × Rs 3 000/year	615 000	
85 skilled or admin. workers × Rs 7 000	595 000	
	= 1 210 000	24.2
Total Annual Expenditure	6 980 000	139.6
INCOME		
Salvage 1% of intake = 1 000 ton × Rs 250	250 000	5.0
NET COST	6 730 000	134.6

If total compost production of 50 000 tons/year was sold at Rs 50 a ton, income would be Rs 2 500 000, and the net cost of refuse disposal Rs 4 230 000, equivalent to Rs 42/ton of wastes received. For most Indian cities this would be an unacceptable level of expenditure.

CHAPTER 19
FINANCIAL EVALUATION OF COMPOSTING METHODS

The four examples of composting plants described in the preceding chapter range in capacity from 3 to 400 tons/day, in capital intensiveness from Rs 1 300 to Rs 65 000/ton of capacity/day (1975 price level), and in method from simple post-treatment to full pre-treatment.

It is probable that compost produced by any of these methods would be similar in essential characteristics, but the cost/ton of compost produced appears to range from Rs 33 to Rs 135/ton based on Indian unit costs (1975 price level). It is not easy to produce accurate comparative costs of the many alternatives and variations which are possible in plant size and extent of mechanization which occur throughout the world. Thus it is necessary to design a standard method based on the unit costs of a city or region, by which systems could be compared in cost.

This requires that all variables other than those arising from the system itself should be excluded by applying standard costs for land and equipment, rates of interest, depreciation, etc. Analysis of the composting process reveals that there are seven easily defined elements, most of which are common to all systems and for which standard costs could be calculated.

The separation of these elements for costing purposes facilitates their application to a wide variety of plant sizes and composting systems.

Section 19.1 defines these elements and suggests performances and costs. In sections 19.2 and 19.3 these standard costs are applied to plants of 3, 50 and 200 tons/day capacity, and for the largest plants pre- and post-treatment are compared.

19.1 Standard costs

The parameters and costs (1975 price level) in the following pages have been derived from many sources: projects prepared by Indian cities, discussions with Indian engineers, and the writer's general experience in India and other countries. Readers should substitute current costs for their own areas when applying the system to a proposed project.

19.1.1 Land, paving, administration and buildings This is cost which is common to all types of plant and is roughly proportional to capacity, as most of the space is occupied by windrows and stored compost.

(1) Land: 200 m^2/ton of refuse intake, cost Rs 100 000/ha.
(2) Site preparation: all sites to be levelled and fenced, and 37.5% of total area paved and drained; inclusive cost Rs 50/m^2 paved area.
(3) Electricity supply to site: for 200 tons/day is based on 100 outlets and 20 exterior lighting columns; it does not include a supply to a treatement plant which is included in plant costs.
(4) Administrative buildings: construction cost of offices and an amenity block, Rs 540/m^2, provision of 25-ton weighbridge with office, Rs 250 000.
(5) Water supply: assumes the provision of a storage tank and 25 mm distribution system (400 metres of pipe for the 200 tons/day plant).
(6) Miscellaneous: includes office furniture, laboratory equipment, hand tools, etc., at the rate of Rs 100 000 for 100 tons/day.
Depreciation in respect of all these items is at 5% year, except light fitting and miscellaneous, which are 10%.
Annual maintenance cost of all items is $1^1/_2$%.

19.1.2 Pre-treatment plant These costs are not universally applicable; they are usually an alternative to post-treatment.

The traditional pre-treatment plant would be composed of the following stages:

— storage hopper with slat conveyor, or bunker with grabcrane,
— elevator and picking belt with overband magnet,
— pulverization by drum, hammermill or rasp,
— screen, and
— ballistic separator.

The general characteristics of such a plant would be:

— each flowline would have a capacity of about 10 tons/hour, which, if operated for 10 hours/day, would give a capacity of 100 tons/day,
— large plants would have multiple flowlines,
— capital cost per flowline would be about Rs 4 000 000 for mechanical and electrical plants and associated civil works (foundations, etc.) equivalent to Rs 40 000/ton of capacity/day.
— installed h.p. would be about 200 per flowline.

Depreciation would be at an annual rate of 10%, and maintenance cost 3%.

19.1.3 Windrowing plant performance and cost Where windrowing is performed manually, performance is estimated to be 5 tons (up to 15 cubic metrés according to density) per man/day.

When windrowing is carried out by mechanical shovels (front-end loaders), it is necessary to use different performances in the case of crude refuse than for pre-treated refuse, the volume of which is reduced by the pulverization process.

(1) Shovel performance with crude refuse:

Bucket capacity 1.0 m^{3*} = 0.4 tons x 320 cycles/day
= 128 tons/shovel/day.

Jobs for 200 tons/day intake:	
stacking	200 tons
turning, 3 x	550 tons (allowing for losses)
removal to plant	150 tons (after decomposition)
selling from stock	100 tons compost
Total task	1 000 tons/day to be handled

For this task 8 machines would be required and a spare would have to be available, i.e., total of 9 front-end loaders.

(2) Shovel performance with pre-treated wastes:

Bucket capacity 0.7 cu. metres = 0.4 ton x 320 cycles/day
= 128 tons/shovel/day.

Jobs for 200 tons/day intake:	
stacking	150 tons
turning, 3 x	400 tons
removal to stockpile	100 tons
selling from stock	100 tons
Total task	750 tons/day to be handled.

For this task 6 machines are needed, plus 1 spare, total 7.

(3) Mechanical shovel operating costs:

Depreciation 1/7th of Rs 170 000	24 300
Interest 6½% (see note later)	11 050
Maintenance, 20% of cost	34 000
Fuel, 20 litres/day = 6 000/year x Rs 1.16	7 000
Driver	5 000
Annual cost	Rs 81 350

19.1.4 Post-treatment plant The type of plant assumed here would be an alternative to the pre-treatment process and would be required where the wastes were windrowed in their crude state. The characteristics of a post-treatment plant are likely to vary with its capacity.

(1) Plants of 200 tons/day (based on Bangalore design, 18.3.):

- storage hopper with slat conveyor,
- elevator and picking belt,
- rasp,
- screen.

Required capacity would be about 60% of that for pre-treatment plants because of weight reduction and density increase arising from decomposition. Thus a single flowline at an estimated cost of Rs 4 000 000 would handle 120 tons/day: this is equivalent to Rs 20 000/ton of capacity/day. Installed h.p. would be about 100.

* Based upon a standard "Escort" 0.7 m^3 bucket fitted with extended tines (say 300 mm) which facilitiate penetration of crude wastes and increase bucket capacity without exceeding permitted maximum weight. Long tines are not suitable, however, for pretreated wastes or finished compost.

(2) Plants of 50 tons/day:

— portable conveyors feeding elevator with picking section,
— screen and ballistic separator.

Cost is estimated to be about Rs 7 000/ton of capacity/day.
(3) Manual plants of 3 tons/day:

— manually operated rotary screen; cost about Rs 1 000/ton of capacity/day.

For all this equipment depreciation is taken at 10% and maintenance 3% a year.

19.1.5 Internal transport Internal transport is required for the movement of wastes between windrows, treatment plant and storage. For example, at a 200 tons/day post-treatment plant trailers would be required on the following scale:

4 stationary trailers to be placed under the following outlet points of the plant: hand-picked contraries, screened contraries, two grades of compost.
= 4 trailers to be exchanged with these when full, total 10 including spares.
4 tractors for towing trailers, total 5 including spares.

Internal transport requirements for pre-treatment would be similar, although the functions would be in a different order.
Tractor trailer costs are as follows:

Item	*Rupees* Tractor	Trailer
Depreciation, 10%, Rs 50 000 & 15 000	5 000	1 500
Interest $6^1/_2\%$, see section 19.1.10	3 250	1 000
Maintenance, 10% of cost	5 000	1 500
Fuel, 15 litres/day × 300 days × Rs 1.16 litre	5 250	
Driver	5 000	
Annual cost	23 500	4 000

19.1.6 Manual workers Drivers are included in vehicle ...e annual cost of other manual labour is assumed to be:

skilled worker	Rs 00/year
unskilled worker	3 000/year

This is an approximate average of a very wide range of labour cost as between rural areas and large cities.

19.1.7 Administration From an examination of several project reports it would appear that the probable cost of managerial, technical, marketing and ancillary services is equivalent to Rs 7/ton of composed produced. This figure would be equally applicable to chain of small rural compost sites organized and supervised on a regional basis.

19.1.8 Other unit costs Water: Rs 5/1 000 gallons. If 200 gallons were used/ton of compost the unit cost is Rs 1/ton of compost.

Electricity: Rs 0.20 kWh.

19.1.9 Hours of operation The hours of operation are assumed to be 300 days/year, 7 hours a day for manual operation and up to 10 hours/day at mechanized plants.

19.1.10 Amortization Depreciation rates vary and have been indicated earlier. They are treated as the equivalent of annual loan repayments. Interest is assumed to be 12% but is calculated on a basis of equal annual loan repayments so that the average interest payment over the total loan period is about $6^1/_2\%$. Amortization is, therefore, as follows:

— for a depreciation rate of 5%: $5\% + 6^1/_2\% = 11^1/_2\%$
— for a depreciation rate of 10%: $10\% + 6^1/_2\% = 16^1/_2\%$

In the following pages comparative figures are given for the evaluation of post and pre-treatment plants of 200 tons/day and post-treatment plants of 3 and 50 tons/day.

19.2 Post and pre-treatment plants of 200 tons/day (1975 price level)

This section provides an example of how the performances and costs which have been given above may be applied to the problem of comparing two plants of different types.

19.2.1 Estimated capital costs

Item	*Rupees*	
	Post-treatment	*Pre-treatment*
Land	400 000	400 000
Site fencing, paving, drainage	750 000	750 000
Administrative buildings		
Offices, etc.	250 000	250 000
Amenities	500 000	500 000
Weighbridge	250 000	250 000
Electricity supply	50 000	50 000
Lighting	50 000	50 000
Water supply	70 000	70 000
Sub-total	2 320 000	2 320 000
Pre-treatment plant, 2 lines × 4 millions		8 000 000

Post-treatment plant, 1 line × 4 millions	4 000 000	
Windrowing plant, shovels 8 or 5	1 360 000	850 000
Internal transport: tractors 5	250 000	250 000
trailers 10	150 000	150 000
Total capital cost	8 080 000	11 570 000

19.2.2 Estimated operating costs

Item	*Rupees* *Annual cost*	*Rs/ton compost*
(1) Land, paving buildings amortization:		
Land, 11½%	46 000	1.530
Paving,	86 300	2.875
Buildings,	115 000	3.830
Electricity supply, 11½%	5 700	0.190
Lighting, 16½%	8 300	0.275
Water supply, 11½%	8 000	0.270
Miscellaneous, 16½%	33 000	1.100
Sub-total	302 300	10.070
Repairs, 1½%*	37 860	1.260
Total	340 100	11.330
(2) Pre-treatment plant:		
Amortization, 16½%	1 320 000	44.000
Repairs, 3%	240 000	8.000
Electricity, 300 kw × LF 80% = 240 kwh × 10 hours × 300 days	144 000	4.800
Total	1 704 000	56.800
(3) Windrowing after pre-treatment:		
Shovels, 7 × Rs. 81 350	569 500	18.950
Water	30 000	1.000
Total	599 500	19.950
(4) Post-treatment plant:		
Amortization, 16½%	660 000	22.000
Repairs, 3%	120 000	4.000
Electricity, 100 kwh × LF 80% = 80 kwh × 10 hours × 300 days.	58 000	1.930
Total	838 000	27.930
(5) Windrowing before post-treatment:		
Shovels, 9	732 200	24.405
Water	30 000	1.000
Total	762 200	25.405
(6) Internal transport:		
Tractors, 5 × 23 500 a year	117 500	3.917
Trailers, 10 × 4 000 a year	40 000	1.333
Total	157 500	5.250

Continued

* NEERI prefers to allow at least 2% for civil and building maintenance.

(7) Manual workers:		
Skilled, 4	28 000	0.933
Unskilled, 50	150 000	5.000
Total	178 000	5.933
(8) Administration	210 000	7.000

19.2.3 Summary of comparative costs

Item	*Post-treatment*		*Pre-treatment*	
	Rs/year	*Rs/ton*	*Rs/year*	*Rs/ton*
Land, etc.	340 100	11.337	340 100	11.337
Pre-treatment	—	—	1 704 000	56.800
Windrowing	762 200	25.405	599 500	19.950
Post-treatment	838 000	27.930	—	—
Internal transport	157 500	5.250	157 500	5.250
Manual workers	178 000	5.933	178 000	5.933
Administration	210 000	7.000	210 000	7.000
Total	2 485 800	82.855	3 189 100	106.270

19.3 Post-treatment plants of 3 and 50 tons/day (1975 price level)

This section provides a comparison between a mainly manual plant of 50 tons/day and an entirely manual plant of 2–3 tons/day, similar to those described in Chapter 7. The use of standard costs produces different results from those given in Chapter 7 which were based on actual local costs and which excluded land cost.

19.3.1 Estimated capital costs

Item	*Rupees*	
	50 t./day	*3 t./day*
Land 1 ha. or 350 sq metres	100 000	3 500
Site fencing, paving, etc., or fencing only	187 500	800
Buildings: office	20 000	—
amenities	50 000	—
Electricity supply	10 000	—
lighting	20 000	—
Water supply	20 000	—
Miscellaneous	60 000	600
Sub-total	467 500	4 900
Post-treatment plant:		
Conveyor belts	200 000	—
Screen	200 000	3 000
Ancilliary structures	40 000	—
Sub-total	340 000	3 000
Windrowing plant:		
Mechanical shovel	170 000	—
Internal transport:		
Tractor, 1	50 000	—
Trailers, 3	45 000	—
Sub-total	95 000	—
Total	1 072 500	7 900

19.3.2 Estimated operating costs

Item	*50 tons/day* *Rs/year*	*Rs/ton*	*3 tons/day* *Rs/year*	*Rs/ton*
(1) Land etc. amortization				
Land 11½%	11 500	1.533	403	1.343
Paving 11½%	21 562	2.875	92	0.307
Office 11½%	2 300	0.307	—	—
Amenities 11½%	5 750	0.767	—	—
Electricity supply 11½%	1 150	0.153	—	—
Lighting 16½%	3 300	0.440	—	—
Water supply 11½%	2 300	0.307	—	—
Miscellaneous 16½%	6 900	0.920	99	0.330
Sub-total	54 762	7.302	594	1.980
Repairs 1½%	7 003	0.933	74	0.247
Total	61 765	8.235	668	2.227
(2) Windrowing, shovel	81 350	10.847	—	—
water	7 500	1.000	300	1.000
Total	88 850	11.847	300	1.000
(3) Post-treatment plant:				
Amortization 16½%	56 100	7.480	495	1.650
Repairs, 3%	10 200	1.360	90	0.300
Electricity, 20 kw, LF 80%	6 720	0.896	—	—
Total	73 020	9.736	585	1.950
(4) Internal transport:				
Tracter, 1	23 500	3.133	—	—
Trailers, 3	12 000	1.600	—	—
Total	35 500	4.733	—	—
(5) Manual workers				
Skilled	7 000	0.933	—	—
Unskilled, 65 or 3	195 000	26.000	9 000	30.000
Total	202 000	26.933	9 000	30.000
(6) Administraton	52 500	7.000	2 100	7.000
Grand total costs	513 635	68.484	12 653	42.177

19.4 Summary of comparative costs (1975 price level)

The following table summarizes the result of using this method of evaluation for the four plants (Cost in Rupees/Ton of compost produced):

Item	*Post-treatment* *3 t./day manual*	*50 t./day manual*	*Pre-treatment* *200 t./day mech*	*200 t./day mech*
(1) Land, paving, etc.,	2.227	8.235	11.330	11.330
(2) Pre-treatment	—	—	—	56.800
(3) Windrowing, loading, etc.	—	11.847	25.405	19.950
(4) Post-treatment plant	1.950	9.736	27.930	—
(5) Manual workers	30.000	26.933	5.933	5 933
(6) Internal transport	—	4.733	5.250	5.250

(7) Administration	7.000	7.000	7.000	7.000
Total expenditure/ton	41.177	68.484	82.855	106.270
Income/ton/day	50.000	60.000	60.000	60.000
LOSS/ton compost	nil	8.484	22.855	46.270
LOSS expressed as disposal cost/ton wastes received	nil	4.242	11.428	23.135
CAPITAL INVESTMENT/ton of capacity/day,	2 600	21 450	41 400	58 850

The first conclusion to be derived is that in present Indian conditions diseconomy of scale applies to composting and that unit costs of compost production increase as plant capacity rises and mechanizations is increased. Thus, to achieve the lowest production cost, a policy of encouraging multiple small, manually operated plants should be followed.

That would not solve the problems of the large urban areas, however, and some mechanization is almost unavoidable for plants receiving 100 tons/day or more of wastes. The most important cost element of the larger plants is for pre-treatment of wastes as received, or for treatment of crude compost after windrowing without prior treatment. If the figures above are reasonably correct (and they must be revised where local conditions are different from the assumptions made by the writer) pre-treatment costs about Rs 57/ton while post-treatment costs much less: about Rs 28/ton. The explanation is very simple: although the plant processes are similar in most respects, a post-treatment plant requires little more than half the volumetric capacity of a pre-treatment plant.

Next in importance is the cost of mechanical handling, stacking, turning and removing windrows and loading compost. Here the cost at pre-treatment plants is less; Rs 20 instead of Rs 26 at post-treatment plants, because pre-treatment reduces the volume to be handled in windrows. More than half of this sum is expended on turning if front-end loaders are employed, but there may be a possibility of reducing this expenditure if *in situ* turning machines are successfully developed.

Perhaps the most important conclusion for India is that the mechanized 200 tons/day post-treatment system disposes of wastes at a cost of about Rs 11/ton. This is roughly the cost that would be incurred in the operation of sanitary landfilling to a good standard. It represents an annual expenditure on wastes disposal (excluding collection) of about Rs 1.5/inhabitant of a city, compared with an annual expenditure of Rs 15/person or more in Europe. It is a viable method of disposal even when the financial constraints of most Indian cities are taken into account.

CHAPTER 20
PLANNING A COMPOST PLANT

20.1 Agriculture

In sections 2.3 to 2.5 the total dependence of a composting plant on support from the agricultural authorities and the surrounding farming community was stressed. Thus the first stage in planning a compost plant is the enlistment of this support in the following tasks:

— the evaluation of the potential compost in relation to local soil conditions and agricultural methods,
— to put a financial value on the compost on the basis of its estimated nutrient content and in terms of equivalent cost of artificial fertilizers,
— to estimate the potential market for compost within its economic transport range.

With co-operation of this kind, the concept can be based on a realistic estimate of the size of the market and the price that could be obtained for the product.

20.2 Analyses and projections

The next requirement is to carry out physical analysis of the wastes, using an accurate sampling method, to obtain the following information:

— density of wastes,
— proportions of salvageable constituents,
— proportions of contrary constituents,
— proportion of constituents that could be incorporated in the compost,
— graded particle size of the compostable wastes.

A compost plant would normally have a life of 15 to 25 years and over such a long period it is likely that changes would occur in the character of the wastes; this could arise from three main causes:

— a rising standard of living increases the production of solid wastes, particularly constituents other than vegetable/putrescible,
— changes in retail distribution and packaging technology may increase the proportion of packaging wastes,

— changes in domestic fuels, for example a reduction in the use of solid fuel, could change physical and chemical characteristics of domestic wastes.

In cities where annual analyses have been carried out for many years, changes of this kind appear on a graph as a fairly smooth curve from which it is usually possible to extrapolate for up to 10 years ahead. Where this information is not available, it is prudent to attempt projections based upon national and local estimates of economic growth and industrialization.

For composting, the two vital constitutents are vegetable-putrescible matter and paper products; most of the others would be removed as salvage or as contraries. In respect of the relative proportions of these two materials, countries fall into three main categories:

Ratio of paper: vegetable/putrescible matter		
Low GNP/head	*Medium GNP/head*	*High GNP/head*
1:20	1:4	2:1
C:N below optimum	C:N about optimum	C:N too high

As GNP/head increases, so does the proportion of paper to vegetable/putrescible matter; thus it is possible to make the following broad generalizations on future wastes characteristics:

— in countries with low GNP/head the character of the wastes will tend to improve for composting purposes,
— in countries with a medium GNP/head the wastes may remain in the optimum range for many years, but the tendency will be towards an ultimate decline in quality,
— where GNP/head is already high, a continuing decline in the composting properties of urban wastes seems to be inevitable.

20.3 Pilot tests

The total period required for the planning, site acquisition, design and tender stage, and erection of a compost plant, is at least two, and often four years. For a comparatively small investment this period can be used to carry out composting on a small scale, with minimum treatment for the following purposes:

— to familiarize senior personnel with problems of windrow management,
— to train at least one junior engineer or chemist in the biochemistry of aerobic composting,
— to train two or three manual workers in the practical handling of wastes, particularly moisture control, during composting,
— to determine optimum windrowing period by daily temperature records for each windrow,
— to test the compost for pathogens, insects and weed seeds to reassure local people as to its hygienic standards.

— to obtain the average N, P and K content of the compost as a partial basis for pricing,
— to produce compost for testing by local agricultural interests and for use in demonstration plots to aid future marketing.

20.3.1 Operation of pilot programme The most convenient scale of operation is one load/day of wastes, of not less than 8 m^3. These loads should be drawn in rotation from different areas of the city so as to represent the average wastes produced.

Each load can be formed into one small windrow and space should be provided for about 20 of them. It may be found possible to reduce the retention period below 20 days after experience has been gained. If the loads are too small to form separate windrows, two may be combined, and the total number will then be only 10.

Each windrow would be built manually and during this process salvage and large contraries would be extracted by hand. Windrows would be turned on the 6th, 11th and 16th days, but there is scope for useful experiment on these iintervals. When decomposition was complete the contents of the windrow would be screened; for this purpose a small rotary screen should be provided, operated manually or by an electric or petrol motor of about one h.p.

The screened compost should then be stored for a few weeks; the minimum period between arrival of the wastes and sale of the compost should be about 40 days. For a daily input of 3 tons, three men would be able to perform all the necessary manual operations.

The physical characteristics of this compost may be inferior to that produced in a more sophisticated plant in one respect: it will contain glass fragments. In other ways, however, it would be fairly representative of the ultimate product.

20.3.2 Use of data In addition to satisfying the objectives listed earlier, such as training, laboratory sampling and field tests, a pilot project could provide valuable data for the final design of the main project.

A useful guide would be obtained on the qualities and quantities of salvage which could be recovered and the prices obtainable.

The proportions of compost and contraries produced would assist in the accurate detail design of mechanical handling elements.

The proportion of oversize compostable matter in the final screen rejects, such as pieces of paper and cardboard, vegetable stalks, etc., which had resisted composition, would provide a measure of the importance of initial size reduction. If such losses were small, the cost of size reduction may not be justifiable in terms of a slightly increased production of compost.

Differences in the composting qualities of wastes from various parts of the city would quickly become apparent. If the compost plant was to handle only a proportion of the city's wastes, it would then be possible to select the most suitable wastes for delivery to the plant, leaving the wastes of lower composting value to be disposed of by landfill.

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However well it may be designed and operated, a compost plant will never be a good neighbour for the following reasons:

— it generates traffic in the form of vehicles delivering wastes and collecting the products of the plant,
— it generates noise from traffic and mechanical plant,
— odour can never be avoided completely; when odours do occur, usually during periods of no wind and high humidity, they are unlikely to be putrid, but they may have a musty character that some people dislike,
— a well operated plant will not produce flies; on the contrary it will destroy them by the million, but, it may attract flies from the immediate neighbourhood of the plant to those areas where fresh wastes are handled,
— the handling of finished compost may give rise to airborne dust.

The location of a site should be on the outskirts of a city in either an industrial or a rural zone; if the former, care should be taken not to put the plant adjacent to factories which may be sensitive to any of the above potential nuisances.

roa
20.4

Location of the site in relation to the road network of the area has three requirements:

— a satisfactory route between the catchment area of the wastes and the plant site,
— good routes from the plant to the main agricultural areas where the compost will be distributed,
— if the site lies off a main road, local access road must be provided.

In most cases it will be necessary to accept a compromise between the first two needs. Where a choice exists, the lowest total transport cost will be attained by locating the plant as close to the city as possible.

site
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20.4

The main requirement is that the major part of the site should be level, dry and possess load-bearing qualities appropriate to the civil and mechanical installations contemplated. If part of the site has two levels, or a steep gradient which could be formed into two levels, it is sometimes possible to use this to advantage by putting the reception area at the upper level, thus avoiding or reducing the amount of excavation required for the storage facility.
The total area of the site is determined by the various treatment and handling phases which may include some or

— roads system and weighbridge,
— mechanical maintenance facilities,
— administration, laboratory and welfare facilities.

The minimum areas required for the simpler systems are about:

40 tons/day	0.75 ha
80 tons/day	1.50 ha
200 tons/day	3.00 ha

The following are desirable features of a compost plant site:

— as far as possible from dwellings,
— space for future expansion,
— a nearby landfill site for disposal of rejects,
— the availability of a water supply from a well, a watercourse, or a main supply.

20.5 Design and tender stage

Throughout the world there are numerous manufacturers of compost plants, each of whom claims special merits for his system. A city which is contemplating the erection of a plant often comes under heavy commercial pressure to adopt a proprietary system on the basis of a "turnkey" project. If open tenders are invited on no more than a capacity basis the tenders are likely to include such a wide range of systems, of very different capital costs, that evaluation on a truly comparable basis becomes almost impossible. In such a case it is common for the lowest tender to be accepted regardless of operating costs or other factors.

There is no single composting process which is universally viable because of the very wide differences which exist between countries at differnt stages of industrial development and in different climates. The vital factors are:

— composition of the wastes,
— initial particle size of the compostable wastes,
— labour costs,
— energy costs,
— indigenous manufacturing capacity,
— the required compost quality.

If the wastes are low in packaging materials and of small average particle size, it may be possible to halve the cost of composting by eliminating pre-treatment. In some countries the turning of windrows mechanically may be much cheaper than manually, but there are many places where the reverse is true. In some situations it may be preferable to employ manual labour, even when it is slightly more expensive than mechanization, in order to avoid the expenditure of scarce foreign exchange on machines and fuel. There are also areas where the over-riding need is to supply the farmer with compost at minimum cost regardless of the contrary content.

For these and other reasons every compost plant should be designed to match local requirements in terms of wastes characteristics, compost quality, and the right balance between capital and labour.

20.5.1 Design stage The purpose of the design stage is to produce a outline design which can serve as the basis for comprehensive tenders a employing the same series of processes. The tenders then are limited to th kind of system required, and evaluation is mainly a matter of caref checking, and comparing costs. The main features of the outline desig would be:

— definition of the required processes,
— capacities of the mechanical elements,
— design constraints (e.g., the maximum speed for a certain conveyo belt),
— specification for roads, building construction and mechanical equip ment,
— general layout of the plant.

The work of the design team would be based upon all the precedin phases of the project which have been discussed: cosultation wit agricultural experts, refuse analyses and projections, the results of a pilo project, all in relation to existing economic constraints.

The design team could be drawn from permanent staff in large cities; fo smaller towns the state environmental agency may be able to provide a team. If adequately trained permanent staff were not available from such sources, it would be necessary to employ consultants.

20.5.2 Tenders The tender documents will be framed in accordance with local usage. Here it is necessary to stress only the importance of incorporating guarantees of performance of the following kind:

— the plant must perform continuously throughout one working day at (say) 10% in excess of rated performance,
— the plant must operate at rated throughput for five successive days,
— the performance of specific elements should be separately guaranteed; for example, in the case of hammermills: the life of a set of hammers in terms of weight of wastes treated, and the average particle sizes of the hammermill product.

The tender price should include the supply of sufficient spare parts for one year's operation after final commissioning, a complete parts list and recommended stock-holding, maintenance manuals for all mechanical elements, and the provision of in-house training for plant operators.

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ANNEX I
PLANNING AND ORGANIZATION OF SOLID WASTES MANAGEMENT SERVICES

The solid wastes management of a city would normally include:

— refuse collection,
— street cleansing and probably gully emptying,
— refuse disposal,
— workshops for vehicles and plant,
— administration: budgetary control, wages, stores, statistics.

In developing countries it has been found that the operation of all these services absorbs from 2 to 5 manual workers/1 000 population and one heavy motor vehicle for about 20 000 population. In certain countries the high ratio of manual workers to population arises through the employment of a large proportion of the workforce on street cleansing; this is sometimes because of inefficient sweeping methods but often because of inadequate refuse collection services, a consequence of which is that a significant proportion of domestic and shop wastes are collected in the form of street refuse.

It is probable that in most cities, given good methods and sound management, efficient services could be provided with a ratio of $2^1/_2$ to 3 manual workers/1 000 population. Even on this scale, however, the labour force to be controlled is very large, about 1 000 men for a city of 400,000 population. The effective deployment of so many workers demands that day-to-day control should be decentralized into partially autonomous groups, each headed by a leader of suitable quality and training.

Thus the basic organization for refuse collection and street cleansing should be a group of about 50 workers controlled by an inspector. The size of this group can be greater—100 or more in densely populated areas but for thse larger groups the inspector requires an assistant. The area controlled by an inspector can be called a district in a city of medium size, a sub-district in a big city.

It is a sound management principle that middle and senior management should control no more than five junior management units. In large cities, therefore, five sub-districts would form one district, headed by a district supervisor; five districts would form a division headed by a divisional superintendent. At the head of this hierarchy will be the officer responsible for the operation of refuse collection and street cleansing within the solid wastes management department.

Such an organization cannot operate efficiently without a physical infrastructure of the following kind:

- — sub-district depots (described earlier in connection with transfer stations),
- — district offices,
- — divisional offices (in large cities),
- — central offices for senior management of the various branches of solid wastes services.

Qualifications for management

In a large city the director of the department and the assistant directors should be enegineers of a discipline appropriate to their main responsibilities, for example:

Operation	Public health engineer
Mechanical services	Mechanical/electrical engineer
Sanitary landfill	Civil engineer
Administrtion	Commerce graduate or economist

For the operational control of refuse collection and street cleanisng, solid wastes management technicians are necessary, having a basic education to high school standard and diploma in solid wastes management. The subjects which should be embraced by such a diploma are suggested in Annex II on training.

Labour relations

A major problem of man-management is that of maintaining the interest of the average worker in his dull and repetitive job. High productivity can be achieved only when motivation is good and some measure of creative satisfaction is provided.

The best approach is that of regular consultation with the workers in order to elicit complaints and suggestions, and also to inform them on management problems and policies, particularly proposals for changes in methods.

The extent to which these consultations are formalized will depend to a large extent on industrial organization. Where most of the men are members of a trade union, consultation will be structured and some of the initiative will come from the workers' representatives.

Even in the absence of unions, consultation and interchange of views should be strongly encouraged at all levels. They are particularly productive at district or sub-district level, because here every man is known personally by the inspector. Senior managers should also consult directly with workers, informally during day-to-day contacts and more formally, perhaps through divisional meetings, when major policy issues need to be discussed.

Health and safety

Management at all levels should be vigilant in providing the maximum protection to workers against risks of accidents and ill-health. The following are important issues:

— the regular use of protective clothing,
— avoiding dangerous methods of riding on vehicles,
— hydraulically tipped vehicle bodies sometimes descend suddenly without warning; men should not stand underneath them.
— all cuts and animal bites should be reported without delay in order that first-aid or medical treatment can be provided,
— personal hygiene should be encouraged by the provision of showers for use before leaving work.

Planning a refuse collection service

The planning and introduction of a re-organized refuse collection service is a complex porcedure that may extend over several years, and it contains four stages:

— a preliminary study to provide guidelines for the testing of what appear to be suitable methods;
— one or more pilot projects to test proposed systems and establish work performances and costs,
— production of a Master Plan based on systems that are successful at pilot scale,
— a phased programme of implementation of the Master Plan.

Preliminary study

The study should have clearly defined objectives which may include:

Health and aesthetic: For example, wastes must not be exposed to vectors, animals or scavengers during storage; collectors must not sustain skin contact with wastes during collection.

Systems: A system must satisfy the specific needs of that area of the city where it is applied; thus multiple systems will probably be necessary.

Mechanization: Labour-intensive methods should be used unless mechanization produces a positive reduction in total expenditure, or is necessary for health protection.

Indigenous equipment: Indigenous vehicles and plant are to be used for at least 90% of all investment.

Productivity: High productivity will be sought by method and time studies and priority given to ensuring high vehicle productivity.

Traffic: Methods should avoid interfering with traffic as far as possible; this implies that animal carts should not be used in the city centre and that motor vehicles should not be parked on the highway for protracted loading periods.

The first step in the preliminary study will be to obtain estimates of wastes generation from the main sources: domestic premises, shops and markets, offices and institutions. Street refuse should also be estimated because it may be handled through refuse collection transfer points. It is also necessary to know the density of the wastes at source, and useful to know the physical constituents. Sampling methods for generation and analysis are described in Chapter 2.

A broad physcial survey of the city is then undertaken, to divide it into areas of similar characteristics on which tentative storage and collection proposals could be based in the light of existing knowledge and available equipment. For each type of area the following issues are considered:

Storage

Communal storage systems of small capacity and short spacing, enclosed, with detachable liners capable of being handled by not more than two men.

Storage in the home, bin capacities for dwellings of various types, and for various collection frequency.

Bin capacities required at shops.

Storage at markets, schools, hotels and other large wastes producers.

Potential use of chutes, and the types of containers to be used in chute chambers.

Responsibility for the provision of containers: owner, occupier or municipality?

Collection:

Frequency of collection for various areas.

Primary collection vehicles: design of handcarts, animal carts, vehicle capacities in relation to density of wastes from various sources.

Short-range transfer systems: trailers, skips, spacing of transfer stations in areas of various population density, design of transfer stations, list of potential sites.

Potential use of crew collection in shopping areas and single dwelling areas: selection of potentially suitable vehicle types.

Potential for mechanized small containers of 1–2 m^3 at schools, hotels and large stores.

Relationship between collection systems and location of disposal site: vehicle capacity in relation to length of haul; relay systems.

At the conclusion of the preliminary study it should be possible to define the main types of area for which different solutions will be necessary, probably ranging from city centre prestige shopping to shack communities, and for each situation one or more tentative proposals together with possible scales of cost.

Pilot projects

The next stage is to test, on a limited scale, the most promising of the possible solutions that have emerged from the preliminary study. The purpose of the pilot tests would be to obtain the following information:

— accurate work performances for manual labour and vehicles, as a basis for route planning at the implementation stage,
— accurate costs, for comparing rival systems, and for accurately estimating investment programme and annual budget,
— to try to judge the impact on health and environmental standards of the systems under test.
— to measure public acceptability of the new systems, without which it would be useless to adopt them.
— to judge the acceptability of the new methods to the workers, because their support is also a vital ingredient.
— to find what modifications are needed to equipment and vehicles.

A pilot project normally requires at least $1^1/_2$ years, because it should run for a complete year in order to cover seasonal changes which occur in wastes generation, and it must be preceded by a period of detailed planning. There may also be delays in acquiring the equipment needed to operate it.

The size of a pilot project is usually determined by the minimum size of an operating unit. For example, the minimum for primary collection by handcart would be one transfer unit, say a trailer; thus about six collectors should be employed, and they would serve about 1 200 dwellings. For communal containers, however, a mere dozen would be sufficient to judge their efficacy, and to obtain standard times for emptying them. Thus the population range for pilot projects may be between 2 000 and 10 000.

It is of the utmost importance that a pilot project should be continuously supervised and detailed results recorded throughout the whole of the test period. Each project may require staffing on the following scale in addition to the workers operating it:

1 project manager,
2 supervisors,
3 recorders, 6 for double-shift operation,
2 social workers.

The social workers have the important task of maintaining a continuous dialogue with residents, to guide them in making the best use of the service being provided in order to gain a high level of co-operation and to measure the acceptability of the method being employed.

Master plan

The results of the pilot projects, judged in the light of cost, public acceptability, and the extent to which primary objectives can be met, can form the basis for a Master Plan which would be implemented by a phased programme over several years.

The Master Plan would define the system to be adopted in every given situation, and would estimate the proportion of wastes from all sources to be handled through each system. On the basis of these estimates, equipment requirements for the whole city can be defined and estimates prepared for capital and operating costs.

The Plan would also establish the geography of operation and control; the locations of transfer points, depots, and offices, and would include standard desgins for depots and transfer stations.

Implementation

Implementation of the Master Plan may involve a complete re-organization of the refuse collection services. It would impose a very heavy managerial load and it would probably be necessary to place the re-organization process in the hands of a special project team with its leader ranked as deputy director, in order to allow normal standards of control of current operations to continue.

Training in the new methods would be necessary for manual workers and technicians; a convenient way of achieving this is to maintain the pilot projects in operation as training grounds during the early period of implementation.

It is probable that a large building programme may be necessary to provide the physical infrastructure for the new methods and it is certain that a large amount of equipment would have to be acquired. The capital expenditure involved is a further reason for phasing implementation over several years.

It is likely that implementation would also involve some changes in the management structure; at the very least some of the boundaries between sub-districts and districts may have to be rationalized. The sub-district or district, having a population in the range of 20 000 to 50 000 is, the recommended basis for re-organization. In the first year it may be prudent to undertake only one or two districts. In a city with 40 districts phasing could be on the following scale:

Year	*Districts*
1	3
2	5
3	9
4	10
5	14

The speeding up of implementation in the later years is possible because detailed route planning can be undertaken continuously by the project team and also because after the first two years a large number of trained personnel will be available for temporary transfer to districts under re-organization.

It should be stressed that implementation requires the same care in planning and supervision as the pilot projects, but for a shorter period. Every collection route must be precisely defined in writing with every single source listed, and during the first few days of operation a supervisor must continuously accompany the collector or the crew, to advise and train them, and to monitor their working rate.

The success of the implementation programme will depend to a large extent on public relations. Every medium should be used to inform the public of the objectives and to advise them on the duties they must perform as part of the service. The best method is always personal contact. Elected representatives should pay visits from house to house in a district under re-organization. Social workers should be involved in areas where there are particular difficulties of communication with the people. The press and radio are obvious methods of instruction and publicity. School teachers should be fully informed about the Master Plan so that it can be discussed in classes.

ANNEX II
TRAINING FOR SOLID WASTES MANAGEMENT

(A memorandum which was approved by the Solid Wastes Management Workshop held at Ahmedabad in October 1975 by the Government of India and WHO).

The following list endeavours to define the required areas of knowledge for officials employed by cities on the management of solid wastes. From such a list it is possible to compile a syllabus for training and examination at different levels of responsibility, e.g:

Technician	(engineering diploma) only subjects marked T and to limited depth.
Professional	(graduate engineer) all subjects.
Post-graduate	(having already covered all subjects) selected specializations to greater depth.

Introductory

T Man in the environment
The closed cycle
Inter-relationship of pollution from all sources
T Solid wastes in relation to public health

Federal and State Law

T Public health legislation as affecting solid wastes
Road transport legislation
Relevant labour laws

Administration

Administrative structure of a department and physical infrastructure (depots, workshop)
T Man-management
T Work study (method and time study)
Cybernetics of relevant manual activities
Office organization and machines

T Statistics and graphs
Cost accounting
Preparation of estimates
T Reports
T Specifications for materials and equipment
Storekeeping systems and records

Solid Wastes Characteristics

T Sources and types of solid wastes: domestic, trade, industrial
T Physical analysis of mixed domestic and trade wastes
T Determination of density and per-capita production
Determination of moisture content and calorific value
Projections of wastes production
Hazardous wastes

Storage and Collection of Solid Wastes

T Determination of collection frequency; the effects of frequency storage and collection
T Manually handled storage containers for dwellings and shops
T Mechanically handled containers for large premises
Refuse chutes
T Communal containers
Expendable containers
T Influence of length of carry, and duties imposed on householders
T Vehicles: man-drawn, animal-drawn, and motor:
design,
optimum radii of operation
T Collection by team:
optimum team size,
vehicle capacity,
work norms,
relay systems,
planning rounds
T Collection by single operators:
work norms,
vehicle capacity,
transfer points,
planning rounds
T Collection of contents of mechanically handled containers
T Exchange systems for hoist or roll-on containers

Street Cleansing

T Origin and character of street refuse
T Road structure in relation to cleansing
T Classification of streets for cleansing purposes

T Manual sweeping:
brooms, shovels and other tools
hand-trucks,
organization
T Gang sweeping, organization
Mechanical sweepers:
pedestrian controlled
highway sweepers
special applications of suction sweepers
T Litter containers, design and siting

Gully and Cesspool Emptying and Street Washing

Designs and application of tanker vehicles with reversible vacuum pumps
organization of routes

Transfer Stations

Inter-relation of collection and disposal systems
Alternative long-distance transport methods
Transfer stations, design and operation

Refuse Disposal

Recycling; pre-separation and recovery
Land-use planning in relation to solid wastes
Principles of refuse treatment:
pulverization,
incineration,
composting, and others
Mechanical elements of treatment plants
Control of pollution transfer
T Disposal on land:
site selection; relations with other public agencies
water pollution control at disposal sites
codes of practice
preparation and planning of site
operation of site: manual methods,
mechanical methods
vector control
biochemistry of deposited wastes
deposit of hazardous wastes
Comparative costs of alternative treatment and disposal methods
Comparative environmental impact of alternative methods

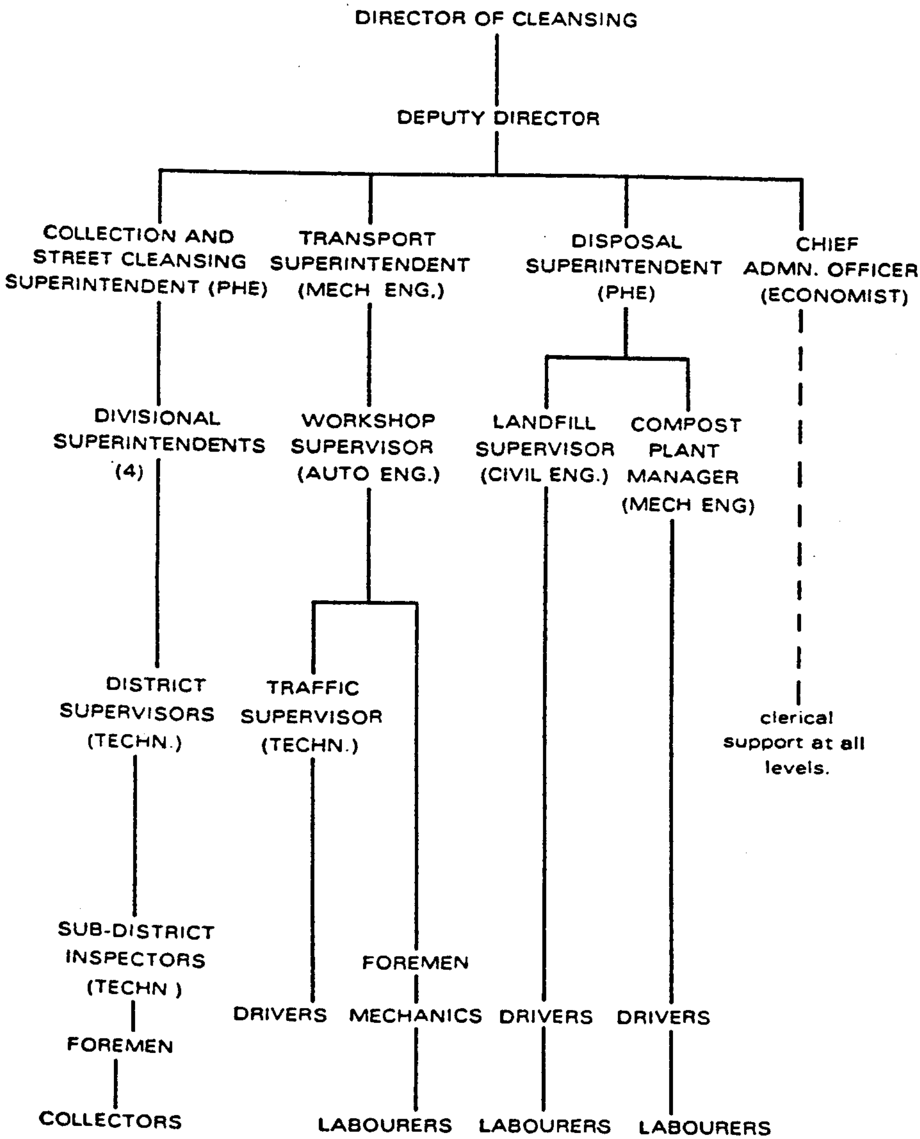
Mechanical and Electrical

An adequate basis of theory is assumed by the entry standard. It is necessary to consider, perhaps at a later stage, provision for training in industrial applications such as treatment plants, and the maintenance of motor vehicles and earth-moving plant. (In Britain training includes several months' experience in workshops.)

To Be Determined

Should an academic body or a professional body determine syllabus and standards?
Duration of courses?
Location of training centres?
Sources of lecturers?
Selection of trainees?
Provision of posts on completion of training?

TYPICAL ORGANIZATION FOR 2,000,000 POPULATION



STAFFING RATIOS FOR SOLID WASTES MANAGEMENT

Ratio	Staff numbers for population of 100,000	Staff numbers for population of 2,000,000
Manual workers 2.5/1,000 population	250	5,000
Foremen 1/10 manual workers	25	500
Inspectors, 1/50 manual workers	5	100
District supervisors, 1/5 Inspectors	—	20
Divisional superintendents, 1/5 District supvrs.	—	4

TYPICAL ORGANIZATION FOR 100,000 POPULATION