CHAPTER 2

PRINCIPLES OF MUNICIPAL SOLID WASTE MANAGEMENT

2.1 INTRODUCTION

Management of municipal solid waste involves (a) development of an insight into the impact of waste generation, collection, transportation and disposal methods adopted by a society on the environment and (b) adoption of new methods to reduce this impact.

2.1.1 Solid Waste Generation

An indication of how and where solid wastes are generated is depicted in a simplified form in Fig. 2.1. Both technological processes and consumptive processes result in the formation of solid wastes. Solid waste is generated, in the beginning, with the recovery of raw materials and thereafter at every step in the technological process as the raw material is converted to a product for consumption. Fig. 2.2 shows generation of solid waste during technological processes involving mining, manufacturing and packaging.

The process of consumption of products results in the formation of solid waste in urban areas as shown in Fig. 2.3. In addition, other processes such as street cleaning, park cleaning, waste-water treatment, air pollution control measures etc. also produce solid waste in urban areas.

A society receives energy and raw material as inputs from the environment and gives solid waste as output to the environment as shown in Fig. 2.1. In the long-term perspective, such an input-output imbalance degrades the environment.

2.1.2 Environmental Impact of Solid Waste Disposal on Land

When solid waste is disposed off on land in open dumps or in improperly designed landfills (e.g. in low lying areas), it causes the following impact on the environment.

(a) ground water contamination by the leachate generated by the waste dump

(b) surface water contamination by the run-off from the waste dump

(c) bad odour, pests, rodents and wind-blown litter in and around the waste dump

(d) generation of inflammable gas (e.g. methane) within the waste dump

(e) bird menace above the waste dump which affects flight of aircraft

(f) fires within the waste dump

(g) erosion and stability problems relating to slopes of the waste dump

(h) epidemics through stray animals

(i) acidity to surrounding soil and

(j) release of green house gas

2.1.3 Objective of Solid Waste Management

The objective of solid waste management is to reduce the quantity of solid waste disposed off on land by recovery of materials and energy from solid waste as depicted in Fig. 2.4. This in turn results in lesser requirement of raw material and energy as inputs for technological processes.

A simplified flow chart showing how waste reduction can be achieved for household waste is shown in Fig. 2.5. Such techniques and management programs have to be applied to each and every solid waste generating activity in a society to achieve overall minimisation of solid waste.

2.2 PRINCIPLES OF MUNICIPAL SOLID WASTE MANAGEMENT

Municipal Solid Waste Management involves the application of principle of Integrated Solid Waste Management (ISWM) to municipal waste. ISWM is the application of suitable techniques, technologies and management programs covering all types of solid wastes from all sources to achieve the twin objectives of (a) waste reduction and (b) effective management of waste still produced after waste reduction.

2.2.1 Waste Reduction

It is now well recognised that sustainable development can only be achieved if society in general, and industry in particular, produces ‘more with less’ i.e. more goods and services with less use of the world’s resources (raw materials

and energy) and less pollution and waste. Production as well as product changes have been introduced in many countries, using internal recycling of materials or on-site energy recovery, as part of solid waste minimisation schemes.

2.2.2 Effective Management of Solid Waste

Effective solid management systems are needed to ensure better human health and safety. They must be safe for workers and safeguard public health by preventing the spread of disease. In addition to these prerequisites, an effective system of solid waste management must be both environmentally and economically sustainable.

- Environmentally sustainable: It must reduce, as much as possible, the environmental impacts of waste management.
- Economically sustainable: It must operate at a cost acceptable to community.

Clearly it is difficult to minimise the two variables, cost and environmental impact, simultaneously. There will always be a trade off. The balance that needs to be struck is to reduce the overall environmental impacts of the waste management system as far as possible, within an acceptable level of cost.

An economically and environmentally sustainable solid waste management system is effective if it follows an integrated approach i.e. it deals with all types of solid waste materials and all sources of solid waste (Fig. 2.6). A multi-material, multi-source management approach is usually effective in environmental and economic terms than a material specific and source specific approach. Specific wastes should be dealt within such a system but in separate streams (as discussed in Section 2.10 and Fig.2.12). An effective waste management system includes one or more of the following options:

(a) Waste collection and transportation.

(b) Resource recovery through sorting and recycling i.e. recovery of materials (such as paper, glass, metals) etc. through separation.

(c) Resource recovery through waste processing i.e. recovery of materials (such as compost) or recovery of energy through biological, thermal or other processes.

(d) Waste transformation (without recovery of resources) i.e. reduction of volume, toxicity or other physical/chemical properties of waste to make it suitable for final disposal.

(e) Disposal on land i.e. environmentally safe and sustainable disposal in landfills.

2.2.3 Functional Elements of Municipal Solid Waste Management

The activities associated with the management of municipal solid wastes from the point of generation to final disposal can be grouped into the six functional elements: (a) waste generation; (b) waste handling and sorting, storage, and processing at the source; (c) collection; (d) sorting, processing and transformation; (e) transfer and transport; and (f) disposal. The inter-relationship between the elements is identified in Fig. 2.7.

Waste Generation: Waste generation encompasses activities in which materials are identified as no longer being of value (in their present form) and are either thrown away or gathered together for disposal. Waste generation is, at present, an activity that is not very controllable. In the future, however, more control is likely to be exercised over the generation of wastes. Reduction of waste at source, although not controlled by solid waste managers, is now included in system evaluations as a method of limiting the quantity of waste generated.

Waste Handling, Sorting, Storage, and Processing at the Source: The second of the six functional elements in the solid waste management system is waste handling, sorting, storage, and processing at the source. Waste handling and sorting involves the activities associated with management of wastes until they are placed in storage containers for collection. Handling also encompasses the movement of loaded containers to the point of collection. Sorting of waste components is an important step in the handling and storage of solid waste at the source. For example, the best place to separate waste materials for reuse and recycling is at the source of generation. Households are becoming more aware of the importance of separating newspaper and cardboard, bottles/glass, kitchen wastes and ferrous and non-ferrous materials.

On-site storage is of primary importance because of public health concerns and aesthetic consideration. Unsightly makeshift containers and even open ground storage, both of which are undesirable, are often seen at many residential and commercial sites. The cost of providing storage for solid wastes at the source is normally borne by the household in the case of individuals, or by the management of commercial and industrial properties. Processing at the source involves activities such as backyard waste composting.

Collection: The functional element of collection, includes not only the gathering of solid wastes and recyclable materials, but also the transport of these materials, after collection, to the location where the collection vehicle is emptied. This location may be a materials processing facility, a transfer station, or a landfill disposal site.

Sorting, Processing and Transformation of Solid Waste: The sorting, processing and transformation of solid waste materials is the fourth of the functional elements. The recovery of sorted materials, processing of solid waste and transformation of solid waste that occurs primarily in locations away from the source of waste generation are encompassed by this functional element. Sorting of commingled (mixed) wastes usually occurs at a materials recovery facility, transfer stations, combustion facilities, and disposal sites. Sorting often includes the separation of bulky items, separation of waste components by size using screens, manual separation of waste components, and separation of ferrous and non-ferrous metals.

Waste processing is undertaken to recover conversion products and energy. The organic fraction of Municipal Solid Waste (MSW) can be transformed by a variety of biological and thermal processes. The most commonly used biological transformation process is aerobic composting. The most commonly used thermal transformation process is incineration.

Waste transformation is undertaken to reduce the volume, weight, size or toxicity of waste without resource recovery. Transformation may be done by a variety of mechanical (eg shredding), thermal (e.g. incineration without energy recovery) or chemical (e.g. encapsulation) techniques.

Transfer and Transport: The functional element of transfer and transport involves two steps: (i) the transfer of wastes from the smaller collection vehicle to the larger transport equipment and (ii) the subsequent transport of the wastes, usually over long distances, to a processing or disposal site. The transfer usually takes place at a transfer station.

Disposal: The final functional element in the solid waste management system is disposal. Today the disposal of wastes by landfilling or uncontrolled dumping is the ultimate fate of all solid wastes, whether they are residential wastes collected and transported directly to a landfill site, residual materials from Materials Recovery Facilities (MRFs), residue from the combustion of solid waste, rejects of composting, or other substances from various solid waste-processing facilities. A municipal solid waste landfill plant is an engineered facility used for disposing of solid wastes on land or within the earth's mantle without creating nuisance or hazard to public health or safety, such as breeding of rodents and insects and contamination of groundwater.

2.3 HIERARCHY OF WASTE MANAGEMENT OPTIONS

Current thinking on the best methods to deal with waste is centred on a broadly accepted 'hierarchy of waste management' (arrangement in order of rank) which gives a priority listing of the waste management options available (see Fig. 2.8). The hierarchy gives important general guidelines on the relative desirability of the different management options. The hierarchy usually adopted is (a) waste minimisation/reduction at source, (b) recycling, (c) waste processing (with recovery of resources i.e. materials (products) and energy), (d) waste transformation (without recovery of resources) and (e) disposal on land (landfilling).

The highest rank of the ISWM hierarchy is waste minimisation or reduction at source, which involves reducing the amount (and/or toxicity) of the wastes produced. Reduction at source is first in the hierarchy because it is the most effective way to reduce the quantity of waste, the cost associated with its handling, and its environmental impacts.

The second highest rank in the hierarchy is recycling, which involves (a) the separation and sorting of waste materials; (b) the preparation of these materials for reuse or reprocessing; and (c) the reuse and reprocessing of these materials. Recycling is an important factor which helps to reduce the demand on resources and the amount of waste requiring disposal by landfilling.

The third rank in the ISWM hierarchy is waste processing which involves alteration of wastes to recover conversion products (e.g., compost) and energy. The processing of waste materials usually results in the reduced use of landfill capacity.

Transformation of waste, without recovery of products or energy, may have to be undertaken to reduce waste volume (e.g. shredding and baling) or to reduce toxicity. This is usually ranked fourth in the ISWM hierarchy.

Ultimately, something must be done with (a) the solid wastes that cannot be recycled and are of no further use; (b) the residual matter remaining after solid wastes have been pre-sorted at a materials recovery facility; and (c) the residual matter remaining after the recovery of conversion products or energy. Landfilling is the fifth rank of the ISWM hierarchy and involves the controlled disposal of wastes on or in the earth's mantle. It is by far the most common method of ultimate disposal for waste residuals. Landfilling is the lowest rank in the ISWM hierarchy because it represents the least desirable means of dealing with society's wastes.

It is important to note that the hierarchy of waste management is only a guideline.

Fig. 2.9 depicts how management of municipal solid waste as per the hierarchy of options leads to progressive reduction of waste reaching the landfill.

2.4 WASTE MINIMISATION

Waste minimisation or reduction at source is the most desirable activity, because the community does not incur expenditure for waste handling, recycling and disposal of waste that is never created and delivered to the waste management system. However, it is an unfamiliar activity as it has not been included in earlier waste management systems.

To reduce the amount of waste generated at the source, the most practical and promising methods appear to be (i) the adoption of industry standards for

product manufacturing and packaging that use less material, (ii) the passing of laws that minimise the use of virgin materials in consumer products, and (iii) the levying (by communities) of cess/fees for waste management services that penalise generators in case of increase in waste quantities.

Modifications in product packaging standards can result in reduction of waste packaging material or use of recyclable materials. Minimisation of use of virgin raw materials by the manufacturing industry promotes substitution by recycled materials.

Sorting at source, recycling at source and processing at source (e.g. yard composting) help in waste minimisation.

One waste management strategy used in some communities in developed countries is to charge a variable rate per can (or ton) of waste, which gives generators a financial incentive to reduce the amount of waste set out for collection. Issues related to the use of variable rates include the ability to generate the revenues required to pay the costs of facilities, the administration of a complex monitoring and reporting network for service, and the extent to which wastes are being put in another place by the generator and not reduced at source.

2.5 RESOURCE RECOVERY THROUGH MATERIAL RECYCLING

Material recycling can occur through sorting of waste into different streams at the source or at a centralised facility. Sorting at source is more economical than sorting at a centralised facility.

2.5.1 Sorting at Source

Sorting at source (home sorting) is driven by the existing markets for recyclable materials and the link between the house holder and the waste collector. The desirable home sorting streams are:

(a) Dry recyclable materials e.g. glass, paper, plastics, cans etc.,

(b) Bio-waste and garden waste,

(c) Bulky waste,

(d) Hazardous material in household waste,

(e) Construction and Demolition waste, and

(f) Commingled MSW (mixed waste).

At present recycling of dry recyclables does take place at the household level in India. However, source separation and collection of waste in streams of (b), (c), (d) and (e) has to be developed in most cities.

2.5.2 Centralised Sorting

Centralised sorting is needed wherever recyclable materials are collected in a commingled (mixed) state.

Hand sorting from a raised picking belt is extensively adopted in several countries.

Mechanised sorting facilities using magnetic and electric field separation, density separation, pneumatic separation, size separation and other techniques are used in some developed countries. Such facilities are usually prohibitively expensive in comparison to hand sorting.

In India, centralised sorting is not adopted. However, some intermediate sorting does occur after household wastes reach kerbside collection bins (dhalaos) through ragpickers. There is a need to formalise this intermediate sorting system or develop a centralised sorting facility to minimise recyclable materials reaching a waste processing facility or a landfill.

2.5.3 Sorting Prior to Waste Processing or Landfilling

Home sorting and centralised sorting processes normally recover most of the recyclable materials for reuse. However, a small fraction of such materials may escape the sorting process. Sorting is also undertaken just prior to waste processing, waste transformation or landfilling to recover recyclable materials. In a landfill, sorting may be carried out by ragpickers immediately after spreading of a layer of waste. In waste processing or transformation centres, manual sorting or size separation is usually undertaken.

Wherever manual sorting is adopted, care must be taken to ensure that sorters are protected from all disease pathways and work in hygienic conditions.

2.6 RESOURCE RECOVERY THROUGH WASTE PROCESSING

Biological or thermal treatment of waste can result in recovery of useful products such as compost or energy.

2.6.1 Biological Processes

Biological treatment involves using micro-organisms to decompose the biodegradable components of waste. Two types of processes are used, namely:

(a) Aerobic processes: Windrow composting, aerated static pile composting and in-vessel composting; vermi-culture etc.

(b) Anaerobic processes: Low-solids anaerobic digestion (wet process), high-solids anaerobic digestion (dry process) and combined processes.

In the aerobic process the utilisable product is compost. In the anaerobic process the utilisable product is methane gas (for energy recovery). Both processes have been used for waste processing in different countries – a majority of the biological treatment process adopted world-wide are aerobic composting; the use of anaerobic treatment has been more limited. Biological processes are discussed in chapter 14 & 15.

In India, aerobic composting plants have been used to process up to 500 tons per day of waste.

2.6.2 Thermal Processes

Thermal treatment involves conversion of waste into gaseous, liquid and solid conversion products with concurrent or subsequent release of heat energy. Three types of systems can be adopted, namely:

(a) Combustion systems (Incinerators): Thermal processing with excess amounts of air.

(b) Pyrolysis systems: Thermal processing in complete absence of oxygen (low temperature).

(c) Gasification systems: Thermal processing with less amount of air (high temperature).

Combustion system is the most widely adopted thermal treatment process world-wide for MSW. Though pyrolysis is a widely used industrial process, the pyrolysis of municipal solid waste has not been very successful. Similarly, successful results with mass fired gasifiers have not been achieved. However both pyrolysis and gasification can emerge as viable alternatives in the future.

Three types of combustion systems have been extensively used for energy recovery in different countries namely: mass-fired combustion systems (MASS), Refuse Derived Fuel (RDF), fired combustion systems and Fluidised Bed (FB) combustion systems are discussed in chapter 15.

To be viable for energy recovery through thermal processing, the municipal solid waste must possess a relatively high calorific value. In the MSW generated in developed countries, presence of significant quantity of paper and plastics yields a high calorific value of the MSW (typically above 2000 kcal/kg) which makes it suitable for thermal processing. In Indian MSW, the near absence of paper and plastics as well as the presence of high quantities of inert material, all combine to yield a low calorific value of the MSW (typically less than 1000 kcal/kg). In its mixed form, such waste may not be suitable for thermal processing. However, removal of inerts from Indian MSW as well as development of combustion system for low-calorific value wastes can result in a reversal of this position in the future.

2.6.3 Other Processes

New biological and chemical processes which are being developed for resource recovery from MSW are:

(a) Fluidised bed bio-reactors for cellulose production and ethanol production.

(b) Hydrolysis processes to recover organic acids.

(c) Chemical processes to recover oil, gas and cellulose.

(d) Others.

The economical viability of these processes is yet to be established.

2.7 WASTE TRANSFORMATION (WITHOUT RESOURCE RECOVERY) PRIOR TO DISPOSAL

At the end of all sorting processes, biological processes and thermal processes, the non-utilisable waste has to be disposed off on land. Prior to this disposal, waste may need to be subjected to transformation by mechanical treatment, thermal treatment or other methods to make it suitable for landfilling.

2.7.1 Mechanical Transformation

Sorting of waste may be undertaken to remove bulky items from the waste. Shredding of waste may be undertaken for size reduction to enable better compaction of waste.

2.7.2 Thermal Transformation

In regions where land space is very scarce (e.g. islands), waste with low calorific value may be subjected to combustion without heat recovery to reduce the volume of waste requiring disposal on land. Combustion transformation processes are similar to those discussed in Section 2.6.2.

2.7.3 Other Methods

To reduce toxicity of wastes e.g. hazardous wastes or biomedical wastes, special detoxification transformations may be undertaken. Some methods used are autoclaving, hydroclaving, microwaving, chemical fixation, encapsulation and solidification. These methods are usually not applied to MSW.

2.8. DISPOSAL ON LAND

Waste is disposed off on land in units called landfills which are designed to minimise the impact of the waste on the environment by containment of the waste. Usually three types of landfills are adopted. Landfills in which municipal waste is placed are designated as “MSW Landfills” or “Sanitary Landfills”. Landfills in which hazardous waste is placed are designated as “Hazardous Waste landfills”. Landfills in which a single type of waste is placed (e.g. only construction waste) are designated as “Monofills”.

2.9 COMPONENTS OF MUNICIPAL SOLID WASTE MANAGEMENT SYSTEM

Fig. 2.10 shows the components of an integrated solid waste management system as applied to municipal solid waste and Fig. 2.11 depicts the detailed structure.

Currently, in India, source separation and collection of dry recyclables is fairly well developed at the household level, commercial centres and institutional areas. These recyclable are further removed by ragpickers at various intermediate stages. Central sorting, whether manual or mechanised, is not adopted.

Source separation of bio-waste, construction and demolition waste as well as hazardous waste is rarely done; consequently most of the waste collected is a mixture of these components. Such mixed waste is rarely suitable for biological

processing or thermal processing as it has high content of inert material, low calorific value and indeterminate mixing of hazardous elements (such as insecticides, paints, batteries etc.) at the micro level.

In some cities, good quality bio-waste is collected from fruit and vegetable markets and subjected to biological processing (aerobic) to produce compost. Such processing plants help reduce the quantity of waste reaching landfills.

Thermal processing of mixed municipal waste has not been successful in India. Biological processing of mixed municipal waste yields low quality compost which may have contaminants in excess of permissible limits.

Biological processing becomes viable once construction and demolition waste and hazardous waste streams are isolated from the bio-waste stream. Thermal processing of waste becomes viable only if sufficient high calorific value components (such as paper, plastic) are present in the waste.

Waste transformation is usually not a major component in an integrated municipal waste management system. However, some sorting and shredding at the landfill site may be undertaken as transformation processes prior to landfilling.

2.10 LINKAGES BETWEEN MUNICIPAL SOLID WASTE MANAGEMENT SYSTEM AND OTHER TYPES OF WASTES GENERATED IN AN URBAN CENTRE

Other than municipal solid waste, the following types of waste may also be generated in urban centres:

(a) Industrial Waste – hazardous and non-hazardous waste from industrial areas within municipal limits.

(b) Biomedical Waste – waste from hospitals, slaughter houses etc.

(c) Thermal Power Plant Waste – Flyash from coal-based electricity generating plant within municipal limits.

(d) Effluent Treatment Plant Waste – Sludge from sewage treatment plants and industrial effluent treatment plants.

(e) Other Wastes – Special wastes from non-conforming areas or special units.

All waste streams must be managed by their own waste management system as shown in Fig. 2.12. However, the following aspects of inter-linkages between different waste streams are considered important.

(a) Different waste streams should not be managed in isolation. Inter-linkages between various streams should be encouraged if these lead to more efficient and economical recovery of the two important resources from solid waste – material and energy. For example, in some countries solid biodegradable waste and sewage are mixed to improve biological processing of solid waste.

(b) Different types of solid waste eventually reach any one of the following three types of landfills – MSW landfills, hazardous waste landfill or monofills for designated waste. Some important observations are:

  (i) All hazardous waste – whether from MSW stream, industrial waste stream or any other waste stream – should be disposed off in "Hazardous Waste Landfills".

  (ii) Large quantity non-hazardous waste (e.g. construction and demolition waste or flyash) should be disposed off in monofills (i.e. "Construction Waste Landfills" or "Ash Disposal Sites").

  (iii) Municipal solid waste after waste processing as well as non-hazardous, small quantity waste (typically less than 15% of the MSW quantity) from non-municipal sources can also be disposed off in MSW landfills, if the compatibility of such wastes with municipal waste is ascertained. Non-hazardous sludge (small quantity) can also be accommodated in a MSW landfill provided it has been dewatered and dried prior to disposal.

(c) At present, the solid waste management practices are to comply with the following sets of regulations:

  (i) Section dealing with conservancy and sanitation in the Municipal Acts of each state.

  (ii) Hazardous Waste Management and Handling Rules (1989), The Ministry of Environment & Forests (MoEF).

  (iii) Biomedical Waste Management and Handling Rules (1998), MoEF.

  (iv) Municipal Solid Waste Management and Handling Rules (Draft) (1998), MoEF.

  (v) Special notifications for other wastes from time to time, MoEF.

The inter-linkages between different waste streams are not clearly identified in these rules and regulations. The municipal solid waste managing authority should ensure that small-quantity waste from other streams is accepted for landfilling only after certification that the waste is non-hazardous by a regulatory authority (e.g. State Pollution Control Board).

2.11 MATERIALS FLOW CHART FOR MUNICIPAL SOLID WASTE MANAGEMENT SYSTEM (1000 t.p.d. WASTE GENERATION)

To develop a solid waste management system for municipal solid waste, the following five steps are involved:

(a) Problem Definition and Statement of Objectives

(b) Inventory and Data Collection

(c) Development of Alternatives

(d) System Selection

(e) Implementation Methodology

The first step involves making a statement of the current problem and the corresponding objectives from decision makers.

The second step involves making an inventory and collecting data pertaining to the existing system as well as that required for the new system. This would involve data relating to waste generation, waste characteristics, transportation routes, collection systems, disposal sites, recycled materials markets etc.

In the third step, the data is evaluated and the feasibility of different technologies examined. Because a problem can have more than one solution, different alternatives are developed.

The alternatives are reviewed by the planners and decision-makers and a final set of technologies/programmes are selected. These set of technologies and programmes constitute the final management system.

The final step is the development of an implementation methodology for conversion of the existing system to the new system. This involves the setting up of schedules as well as monitoring mechanisms for implementation by the administrative organisations.

At the macro-level, the end result of an integrated waste management system is the development of materials flow chart, which shows how the waste is sorted, processed and transformed prior to disposal in a landfill. Two such flow charts are shown in Figs. 2.13 and 2.14. Fig. 2.13 shows a materials flow chart in a community generating 1000 TPD of waste without application of ISWM. Fig. 2.14 shows a materials flow chart developed based on the principles of ISWM for the twin objectives of (a) waste reduction and (b) effective management of waste still produced. The flow chart is conceptual in nature and does not suggest preference for any set of technologies. It is based on the assumption that the waste has about 17.5% recyclable material, 54% compostable material, 13.5% combustible material and the balance 15% as rejects. The materials flow chart for any system would have to be established on a case-to-case basis taking into account of (a) the waste quantities and characteristics at present, (b) the influence of sorting at source, intermediate/central sorting on the waste quantities and characteristics and (c) the applicability of various technologies to post-sorted waste. Since developments in waste processing are taking place at a rapid pace, the onus of demonstrating the feasibility of a technology usually lies with the technology supplier. The role of the planner and the decision-maker is usually to ensure that post-processing products in the gaseous, liquid and solid states meet the desired environmental standards.