MINISTRY OF URBAN DEVELOPMENT

CENTRE OF EXCELLENCE IN URBAN DEVELOPMENT

in the area

SOLID WASTE AND WASTE WATER MANAGEMENT

SOLID WASTE MANAGEMENT TECHNOLOGY MANUAL

CENTRE FOR ENVIRONMENT AND DEVELOPMENT

THIRUVANANTHAPURAM

OCTOBER 2011

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SWM TECHNOLOGY MANUAL

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PREFACE

The Ministry of Urban Development (MoUD), Government of India, through its activities proposed under the Capacity Building Scheme for Urban Local Bodies (CBULB) established Centres of Excellence (CoE) in reputed institutions in the country to create the necessary knowledge base for improving municipal service delivery and management. The establishment of CoEs is an acknowledgement of the need for high quality Indian-context-specific research and creative interventions in the areas of governance, institution and capacity building, citizen-centric administration and resource and performance management. In establishing the CoEs, the MoUD expected that the CoEs would be able to find solutions to the many issues faced by Urban India. The basic objective of the CoEs is to foster cutting-edge and crosscutting research, capacity building and technical knowledge base in the area of urban development. The CoEs will address urban development issues at national, state and local levels and will provide support to state and local governments in:

The MoUD has approved a project to Centre for Environment and Development to set up a Centre of Excellence on 'Solid Waste and Waste Water Management '. The basic objective was to develop the capacity of the institution to support the Urban Local Bodies(ULB) in the country on solid waste and waste water management related activities. The CoEs will work with selected ULBs to develop strategies and framework to implement activities.

The CoE at CED which is concentrating on 'Solid Waste and Waste Water Management' has been focusing on three major aspects (i) Development of Strategy and Framework for Solid Waste and Waste Water Management in ULBs (ii) Capacity Building, Training and Awareness and (iii) Development of Knowledge Centre and Technical Support Unit on Solid Waste and Waste Water Management. CED is also working with Thiruvananthapuram City Corporation and Payyannur Municipality on these two sectors and trying to integrate the field experience to develop the strategy and framework.

The CoE team at CED has developed eight Resource Materials on SWM such as (1) Strategy and Framework for MSW Management (2) SWM Technology Manual (3) Operation and Maintenance Manual (4) Byelaw for ULBs on Solid Waste(Handling &Management) (5) Strategy and Framework for Wastewater Management,(6) Course Material on Solid Waste Management (7) Course Material on Wastewater Management and (8) Capacity Building and Training Manual. These documents had already submitted to MoUD and also to ASCI for Peer Review and their comments has also been incorporated in this final document.

The Technology Manual on SWM is mainly to provide technology information to decision makers, planners and senior level officers to take scientific decisions on the choice and selection of technology, technical information during implementation and to monitor the process of SWM form time to time. It explains the technologies suitable to Indian condition, technical details and design specifications and operational aspects, etc and also model estimates to set up composting technology. The manual is prepared using the secondary information already available and also integrating the experiences of CED in working with the ULBs in general and Thiruvananthapuram and Kochi City Corporations and Payyannur Municipality in particular. CED is operating two major SWM systems each with a capacity to process 300 MTs/Day with all auxiliary components like RDF, Leachate Treatment Plant, etc and also carrying out many research studies to improve the functioning of the SWM system. These hands on experience through operation and management of the system and in planning and design of SWM system in many ULBs and Panchayats has been integrated in preparing this Manual.

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1. INTRODUCTION

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 and less pollution and waste. Efficient delivery of public services and infrastructure are pressing issues for municipalities in most developing countries; and in many countries, solid waste management(SWM) has become a top priority. SWM is costly and complex for local governments, but it is so essential to the health, environment and quality of life of the people. They must be safe for workers and safeguard public health by preventing the spread of diseases. In addition to these prerequisites, an effective system of solid waste management must be both environmentally and economically sustainable. SWM is a system for handling of all types of garbage. The end goal is a reduction of the amount of garbage clogging the streets and polluting the environment, whether that garbage is disposed of or recycled into something useful.

The process of SWM has two important streams of activities such as the social engineering and technology applications. The major element of social engineering is the participation of the community in the process and their involvement in the proper management of the wastes as well as adopting the 4R concept to the maximum extent possible. The technology application deals with the use of appropriate technology for processing and disposal of solid wastes leading to resource recovery and to improve the environment. There are many technology options available to process different types of wastes and also depending on the kind of resource recovery planned.

The suitability of a particular technology for the treatment of Municipal Solid Waste Management (MSW) depends on a number of factors that essentially include techno -economic viability, environmental safeguards, sustainability and location specificity. The important parameters that are considered generally for a suitability analysis are the quantity of waste that can be handled by a technology, physical, chemical and biological character istics of waste, land and water requirement, environmental sensitivity to locations, environmental impacts/pollution potential, capital investment, O&M costs, cost-recovery, product utility, by-product usability, reject disposal, requirement of pollution control installation, etc. The suitable technologies are location specific and vary from place to place.

The technology options available for processing the MSW are based on either bioconversion or thermal conversion (Diaz et al., 2002; Benedict et al., 1998; Corey,1969; Tchobanoglous, 2003; UNEP, 2005; Salvato,1992).The bio-conversion method is applicable to the organic fraction of wastes, to form compost or to generate biogas such as methane (waste to energy) and residual sludge (manure). Various technologies are available for composting such as aerobic, anaerobic and vermi composting. The thermal conversion technologies are incineration with or without heat recovery, pyrolysis and gasification, plasma pyrolysis and pelletization or production of Refuse Derived Fuel (RDF). The solid waste management options depend on many factors such as quantity of generation, characteristics of waste, local climatic con ditions, availability of land and other infrastructure, manpower availability, etc. The concept of decentralized waste management especially at the source of generation itself is the best option but this may not be possible everywhere especially in large cities, where we may have to go for centralized systems combined with decentralized programmes. Considering the characteristics of waste produced in India (nearly

70% is biodegradable and predominantly with high wetness) Composting and Biomethanation are the best suited technology options for degradable wastes.

2. COMPOSTING

Composting is one of the important technologies for Solid Waste Management (SWM). Any organic material that can be biologically decomposed is compostable. In fact, human beings have used this naturally occurring process for centuries to stabilize and recycle agricultural and human wastes. Today, composting is a diverse practice that includes a variety of approaches, depending on the type of organic materials being composted and the desired properties of the final product. To derive the maximum benefit from the natural, but typically slow decomposition process, it is necessary to control the environmental conditions during the composting process. The overall composting process can be explained as follows:

Organic matter + O_2 + aerobic bacteria $\longrightarrow$ CO_2 + NH_3 + H_2O + Other end products + energy

Compost is the end product of the composting process. The by-products of this process are carbon dioxide,ammonia and water. Compost is peaty humus, dark in colour and has a crumbly texture, an earthy odour, and resembles rich topsoil. Compost will not have any resembles in the physical form to the original waste from which it was derived. High-quality compost is devoid of weed seeds and organisms that may be pathogenic to humans, animals, or plants. Cured compost is also relatively stable and resistant to further decomposition by microorganisms.

As mentioned earlier, the composting process is an environmentally sound and beneficial means of recycling organic materials and not a means of waste disposal. It is important to view compostable materials as usable and not as waste requiring disposal. A major portion of municipal solid wastes in India contain upto 70% by weight of organic materials. In addition, certain industrial by-products-those from food processing, agricultural and paper industries – are mostly composed of organic materials.

(i) Composting Processes

Several factors contribute to the success of composting including physical, chemical and biological processes. Understanding these processes, therefore, is necessary for making informed decisions, when developing and operating a composting programme.

Biological Processes

Microorganisms such as bacteria, fungi and actinomycetes as well as larger organisms such as insects and earthworms play an active role in decomposing the organic materials. As microorganisms begin to decompose the organic material, they break down organic matter and produce carbon dioxide, water, heat and humus (the relatively stable organic end product). This humus end product is compost.

Composting proceeds through the following four phases:

- **Mesophilic or moderate-temperature phase:** Compost bacteria combine carbon with oxygen to produce carbon dioxide and energy. The microorganisms for reproduction and growth use some of the energy and the rest is generated as heat. When a pile of organic refuse begins to undergo the composting process, mesophilic bacteria proliferate, raising the temperature of the composting mass up to 44°C. This is the first stage of the composting process. These mesophilic bacteria can include E. coli

and other bacteria from the human intestinal tract, but these soon become increasingly inhibited by the temperature, as the thermophilic bacteria take over in the transition range of 44-52°C.

- **Thermophilic or high-temperature phase**: In the second stage of the process, the thermophilic microorganisms are very active and produce heat. This stage can continue up to about 70° C, although such high temperatures are neither common nor desirable in compost. This heating stage takes place rather quickly and may last only a few days, weeks, or months. It tends to remain localized in the upper portion of a compost pile where the fresh material is being added, whereas in batch compost, the entire composting mass may be thermophilic all at once. After the thermophilic heating period, the manure will appear to have been digested, but the coarser organic material will not be digested. This is when the third stage of composting, i.e., the cooling phase, takes place.

- **Cooling phase**: During this phase, the microorganisms that were replaced by the thermophiles migrate back into the compost and digest the more resistant organic materials. Fungi and macroorganisms such as earthworms and sow bugs that break the coarser elements down into humus also move back in.

- **Maturation or curing phase**: The final stage of the composting process is called curing, ageing, or maturing stage, and is a long and important one. A long curing period (e.g., a year after the thermophilic stage) adds a safety net for pathogen destruction. Many pathogens have a limited period of viability in the soil, and the longer they are subjected to the microbiological competition of the compost pile, the more likely they will die a swift death. Immature compost can be harmful to plants. Uncured compost can, for example, produce phytotoxins (i.e., substances toxic to plants), robbing the soil of oxygen and nitrogen and contain high levels of organic acids.

Chemical Processes

Several factors determine the chemical environment for composting. These include the presence of an adequate carbon food/energy source, a balanced amount of nutrients, the correct amount of water, adequate oxygen, appropriate pH and the absence of toxic constituents that could inhibit microbial activity. A brief description of each of these factors is given below:

- **Carbon/energy source**: For their carbon/energy source, microorganisms in the composting process rely on carbon in the organic material, unlike higher plants that rely on carbon dioxide and sunlight. Since most municipal and agricultural organics and yard trimmings contain an adequate amount of biodegradable forms of carbon, it is not a limiting factor in the composting process. As more easily degradable forms of carbon are decomposed, a small portion of the carbon is converted into microbial cells, and a significant portion is converted to carbon dioxide and lost to the atmosphere. As the composting process progresses, the loss of carbon results in a decrease in weight and volume of the feedstock.

- **Nutrients**: Among the plant nutrients (i.e., nitrogen, phosphorous and potassium), nitrogen is of greatest concern, because it is lacking in some plant materials. The carbon-nitrogen ratio, which is established on the basis of available carbon rather than total carbon, is considered critical in determining the rate of decomposition. Leaves, for example, are a good source for carbon, and fresh grass, manure and slaughter house waste are the sources of nitrogen. To aid the decomposition process, the bulk of the organic matter should be carbon with just enough nitrogen. In general, an initial ratio of 30:1(C:N or

Carbon: Nitrogen) is considered ideal. Higher ratios tend to retard the process of decomposition, while ratios below 25:1 may result in odour problems. Finished compost should have ratios of 15 to 20:1. Adding 3 – 4 kg of nitrogen material for every 100 kg of carbon should be satisfactory for efficient and rapid composting. To lower the carbon to nitrogen ratios, nitrogen-rich materials such as yard trimmings, animal manures, or bio-solids are often added. Adding partially decomposed or composted materials (with a lower carbon: nitrogen ratio) as inoculums may also lower the ratio. As the temperature in the compost pile rises and carbon- nitrogen ratio falls below 25:1, the nitrogen in the fertilizer is lost as gas (ammonia) to the atmosphere. The composting process slows, if there is not enough nitrogen, and too much nitrogen may cause the generation of ammonia gas, which can create unpleasant odours.

- **Moisture**: Water is an essential part of all forms of life, and the microorganisms living in a compost pile are no exception. Since most compostable materials have lower than ideal water content, i.e., 50 to 60% of total weight, the composting process may be slower than desired, if water is not added. However, it should not be high enough to create excessive free flow of water and movement caused by gravity. Excessive moisture and flowing water form leachate, which creates potential liquid waste management problems including water and air pollution (e.g., odour). For example, excess moisture impedes oxygen transfer to the microbial cells, can increase the possibility of developing anaerobic conditions and may lead to rotting and obnoxious odours.

Controlling the size of piles can minimize evaporation from compost piles, as piles with larger volumes have less evaporating surface/unit volume than smaller piles. The water added must be thoroughly mixed so that the organic fraction in the bulk of the material is uniformly wetted and composted under ideal conditions. Properly wetted compost has the consistency of a wet sponge. Systems that facilitate the uniform addition of water at any point in the composting process are preferable.

- **Oxygen**: Composting is considered as an aerobic process. Decomposition can occur under both aerobic (requiring oxygen) and anaerobic (in the absence of oxygen) conditions. The compost pile should have enough void space to allow free air movement so that oxygen from the atmosphere can enter the pile and the carbon dioxide and other gases emitted can be exhausted to the atmosphere. To maintain aerobic conditions, in which decomposition occurs at a fast rate, the compost pile is mechanically aerated or turned frequently to expose the microbes to the atmosphere and to create more air spaces by fluffing up the pile.

A 10 to 15% oxygen concentration is considered adequate, although a concentration as low as 5% may be sufficient for leaves. While higher concentrations of oxygen will not negatively affect the composting process, circulation of an excessive amount of air can cause problems. For example, excess air removes heat, which cools the pile and also promotes excess evaporation. In other words, excess air slows down the rate of composting. Excess aeration is also an added expense that increases production costs.

- **pH:** The pH factor affects the amount of nutrients available for the microorganisms, the solubility of heavy metals and the overall metabolic activity of the microorganisms. A pH between 6 and 8 is considered optimum, and it can be adjusted upward by the addition of lime, or downward with sulphur, although such additions are normally not necessary. The composting process itself produces carbon dioxide, which, when combined with water, produces carbonic acid, which could lower the pH of the

compost. As the composting process progresses, the final pH vary, depending on the specific type of feedstock used and operating conditions. Wide swings in pH are unusual since organic materials are naturally well buffered with respect of pH changes.

Physical Processes

- **Particle size**: Smaller particles usually have more surface area per unit weight, they facilitate more microbial activity on their surfaces, which leads to rapid decomposition. The optimum particle size has enough surface area for rapid microbial activity and also enough void space to allow air to circulate for microbial respiration.

- **Temperature**: Composting can occur at a range of temperatures, and the optimum temperature range is between 32 and 60°C. Temperatures above 65°C are not ideal for composting as thermal destruction of cell proteins kills the organisms. Similarly, temperatures below the minimum required for a group of organisms affect the metabolic activity (i.e., regulatory machinery) of the cells.

When compost is at a temperature greater than 55°C for at least three days, pathogen destruction occurs. It is important that all portions of the compost material are exposed to such temperatures to ensure pathogen destruction throughout the compost. Attaining and maintaining 55°C for three days is not difficult for invessel composting system.

However, to achieve pathogen destruction with windrow composting systems, the 55°C temperature level must be maintained for a minimum of 15 days. The longer duration and increased turning are necessary to achieve uniform pathogen destruction in the entire pile.

- **Mixing:** Mixing of feedstock, water and inoculants is important and is done by running or mixing the piles after composting has begun. Mixing and agitation distribute moisture and air evenly, and promote the breakdown of compost clumps. Excessive agitation of open vessels or piles, however, can cool them and retard microbial activity.

(ii) Steps of Composting

There are five basic steps involved in all composting practices, namely preparation, digestion, curing, screening or finishing, and storage or disposal.

However, differences (among various composting processes) may occur in the method of digestion or in the amount of preparation and the finished product.

Preparation

The preparation phase of composting involves several steps, and these depend upon the sophistication of the plant and the amount of resource recovery practiced. A typical preparation process, however, may include activities such as the sorting of recyclable materials, the removal of non-combustibles, the shredding, pulping, grinding and the adding of water sludge.

The separation of other non-compostable recyclable materials like glass, metal, rag, plastic, rubber and paper may be accomplished by either hand or mechanical means. Since the refuse characteristics vary from one load to the next, a final step in the preparation phase of composting may be to adjust the moisture and nitrogen content of the solid waste to be composted.

The optimum moisture content ranges from 45 to 55% of wet weight, while the optimum carbon to nitrogen ratio should be below 30%. The moisture and nutrient adjustments can be accomplished most efficiently through the addition of raw waste water sludge. This increases the volume of composted material by 6 to 10%, in addition to accelerating the composting operation and producing a better final product in terms of nutrient contents.

Digestion

Digestion techniques are the most unique feature of the various composting processes and may vary from the backyard composting process to the highly controlled mechanical digester. Composting systems fall into the following two categories (i) Window composting in open windrows (ii) Mechanical composting in enclosed digestion chambers.

Curing

During curing, the compost becomes biologically stable, with microbial activity occurring at a slower rate than that during actual composting. Curing piles may be either force-aerated or passive aerated with occasional turning. As the pile cures, the microorganisms generate less heat and the pile begins to cool. Cooling is merely a sign of reduced microbial activity, which can result from lack of moisture, inadequate oxygen within the pile, nutrient imbalance or the completion of the composting process. Curing may take from a few days to several months to complete. The cured compost is then marketed.

Screening or finishing

Compost is screened or finished to meet the market specifications. Sometimes, this processing is done before the compost is cured. One or two screening steps and additional grindings are used to propagate the compost for markets. During the composting operation, the compostable fraction separated from the non-compostable fraction, through screens, undergoes a significant size reduction.

The non-compostable fraction retained on the coarse screen is sent to the landfill, while the compostable materials retained on finer screens may be returned to the beginning of the composting process to allow further composting. The screened compost may contain inert particles such as glass or plastic that may have passed through the screen. The amount of such inert materials depends on feedstock processing before composting and the composting technology used.

To successfully remove the foreign matter and recover the maximum compost by screening, the moisture content should be below 50%. Drying should be allowed only after the compost has sufficiently cured. If screening takes place before curing is complete, moisture addition may be necessary to cure the compost. The screen size used is determined by market specifications of particle size.

Storage or disposal

In the final analysis, regardless of the efficiency of the composting process, the success or failure of the operation depends upon the method of disposal. Even when a good market for compost exists, provision must be still made for storage.

Storage is necessary because the use of composting is seasonal, with greatest demand during spring and winter. Therefore, a composting plant must have a 6-month storage area. For a 300 tonne per day plant, it will require about six hectares of storage area.

(iii) Composting Technologies

The first significant development in composting as a systemized process took place in India during 1925, when a process involving the anaerobic degradation of leaves, refuse, animal manure and sewage were placed in pits. The materials were placed in layers and the pit wall conserved some of the heat of degradation, resulting in high temperature than when composting was carried out in the open.

This process (often referred as Indore process) took approximately six months to produce usable compost. Following this, the Indian Council of Agricultural Research (ICAR) improved the method by laying down alternate layers of waste and sewage and this system (referred to as the Bangalore Method) is still being used in India. In India, the high humid degradation that occurs in the land requires a large amount of humus for maintaining soil-fertility, and for that reason, composting is an ideal method for recycling organic wastes.

The composting technologies – windrow, aerated static pile, in-vessel composting, vermi composting and anaerobic processing– vary in the method of aeration, temperature control, mixing/turning of the material, time required for composting, and capital and operating costs. There are also some supporting technologies, which include sorting, screening and curing.

There are four general categories of composting technologies which are described below:

Windrow Composting

Windrow composting is the most common technology implemented in most of the ULBs in the country. Windrows are defined as regularly turned elongated piles, trapezoidal in cross section and upto a hundred meters or more in length. The cross-sectional dimensions vary with feedstock and turning equipment, but most municipal solid waste (MSW) windrows are 1.5 to 2 meters high and 3 to 6 meters wide. The sketch of composting plant is given in Fig. 1

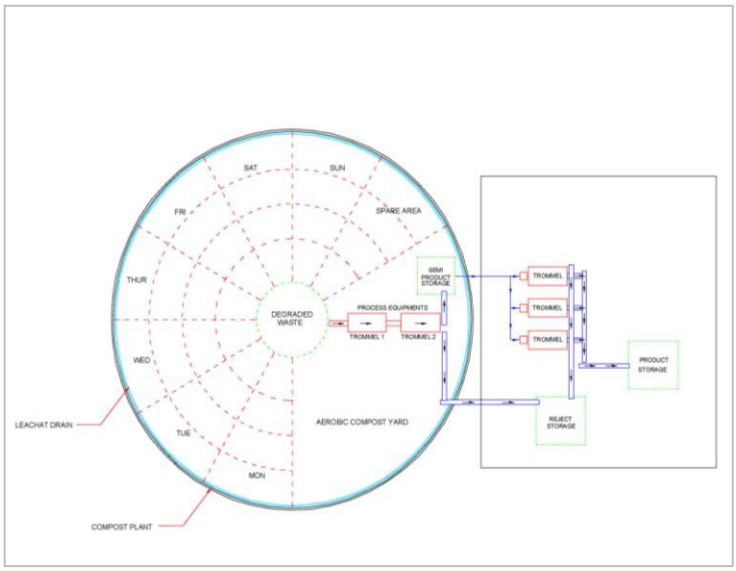


Fig.1 : Sketch of Windrow Compost Plant

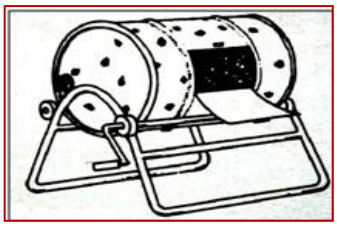
Windrows composed of MSW are usually required to be located on an impermeable surface. The optimum size and shape of the windrow depends on particle size, moisture content, pore space and decomposition rate – all of which affect the movement of oxygen towards the centre of the pile. Turning the pile re-introduces air into the pile and increases porosity so that efficient passive aeration from atmospheric air continues at all times. The windrow dimensions should allow conservation of the heat generated during the composting process and allow air to diffuse to the deeper portions of the pile. They may be turned as frequently as once per week, but more frequent turning may be necessary, if high proportions of bio-solids are present in the feedstock. The specifications and design criteria for windrow compost plant is given as Annexure -1 and the design and layout of windrow compost plants of varying capacities is given as Annexure-2.The estimated cost for establishment of windrow compost plants of varying capacities is given as Annexure-3

Aerated Static Pile Composting

Aerated static pile composting is a non-proprietary technology that requires the composting mixture (i.e., a mixture of pre-processed materials and liquids) to be placed in piles that are mechanically aerated. The piles are placed over a network of pipes connected to a blower, which supplies the air for composting.

Air circulation in the compost piles provides the needed oxygen for the composting microbes and prevents excessive heat build-up in the pile. Removing excess heat and water vapour cools the pile to maintain optimum temperature for microbial activity. A controlled air supply enables construction of large piles, which decreases the need for land. Odours from the exhaust air could be substantial, but traps or filters can be used to control them. The temperatures in the inner portion of a pile are usually adequate to destroy a significant number of the pathogens and weed seeds present. The surface of piles, however, may not reach the desired temperatures for destruction of pathogens because piles are not turned in the aerated static pile technology. This problem can be overcome by placing a layer of finished compost of 15 to 30cm thick over the compost pile. The outer layer or finished compost acts as an insulating blanket and helps maintain the desired temperature for destruction of pathogens and weed seeds throughout the entire pile. When the composting process is nearly complete, the piles are broken up for the first time since their construction. The compost is then taken through a series of post-processing steps. Producing compost using this technology usually takes about 6 to 12 weeks.

In Vessel Composting System



In-vessel composting systems enclose the feedstock in a chamber or vessel that provides adequate mixing, aeration and moisture. Drums, digester bins and tunnels are some of the common in-vessel type systems. In some cases, the vessel rotates, and in others, it is stationary and a mixing/agitating mechanism moves the material around. Most in-vessel systems are continuous-feed systems,

although some operate in a batch mode. A major advantage of in-vessel systems is that all environmental conditions can be carefully controlled to allow rapid composting.

The design and operational specifications of aerobic composting is given in Table.1

Table. 1

Design and Operational Specifications of Aerobic Composting Process

No	Aspects	Preferable standards and specifications
1	MSW characteristics	Sorted organic fraction of MSW, preferable with the same rate of decomposition
2	MSW Particle size	Between 25 – 75 mm for optimum results
3	C/N Ratio	Between 25 – 50 initially. Release of ammonia and impeding of biological activity at lower ratios. Nitrogen as a limiting nutrient at higher ratios
4	Blending & Seeding	Addition of partially decomposed matter (1-5% by weight) reduces composting time.
5	Moisture content	55% (optimum)
6	Windrow size	3 m length, 2 m width and 1.5 m height (optimum)
7	Mixing/turning	Every four or five days, until the temperature drops from about 66 – 60°C to about 38°C or less. Alternate days under typical operating conditions
8	Temperature	50-55°C for first few days and 55-60°C for the reminder composting period. Biological activity reduces significantly at higher temperature (>66°C)
9	Pathogen control	Maintenance of temperature between 60-70°C for 24 hours
10	Air requirement	Air with at least 50% of initial oxygen concentration to reach all parts of composting material
11	pH control	7 – 7.5 (optimum). Not above 8.5 to minimize nitrogen loss in the form of ammonia gas
12	Inoculums	Not desirable, except in special cases
13	Degree of decomposition	Determine by Chemical Oxygen Demand(CED) test or from Respiratory Quotient (RQ).
14	Area requirement	~25 m^2 for 1 ton of MSW (only for windrow formation for 21 days composting and maturity yard for 30 days stabilization). Area for machinery, packing and storage extra
15	Post treatment care	Facility for effluent (leachate) recycling and treatment and sanitary landfill of rejects (inert materials, sludge from Effluent Treatment Plant(ETP)
16	Nutrient recovery	2-4 kg N/ton; 1-2 kg P/ton; 1-2 kg K/ton
17	Product recovery	18-25% of waste input
18	Residuals for disposal	2-20% sieving overflow (plastic, metal, glass, stones, uncomposted matter

Source: Varma, A.K, 2008

Vermi Composting

Vermi composting is a modified and specialised method of composting and it is the end product of the breakdown of organic matter by some species of earthworm. Vermicompost is a nutrient- rich, natural fertilizer and soil conditioner. The earthworm species most commonly used are *Eudrillus eugineae*, *Eisenia foetida* or *Lumbricus rubellus.*

A by-product of vermi composting called vermiwash (which can be collected if there is a tap at the base of the vermi compost tank) also serves the same purpose. Small scale vermi composting is done in bins of varying sizes and style and three different types of practices such as non- continuous, continuous vertical flow and continuous horizontal flow are adopted.

The methods for large scale vermi composting are windrow and raised-bed or flow through systems. Flows through systems are well suited to indoor facilities, making them the preferred choice for operations in colder climates. Kitchen wastes except oily and spicy items are suitable for worms. But too much kitchen waste leads to putrification before worms can process it and becomes harmful to the worms.

Similarly, material sprayed with pesticides, high water content materials like watermelon, woody part of garden wastes, etc., are preventing the process. Regular removal of composted material, adding holes to bins or using continuous-flow bin, etc., improve oxygen supply to worms.

The design and operational aspects of vermin composting process is given in table.2 An important point to note in case of vermin composting but widely ignored, is to carry out proper sieving of the compost before applying it in the fields. In the usual way vermin composting is practiced now is both labour-intensive and requires some infrastructure. However, in household level it is found very effective.

The study carried out by Centre for Environment and Development showed that plastic tumbler and Ferro-cement boxes can be used effectively for vermi composting at household level. The solid waste at household level shall be managed by taking compost pits or by (where ever land is available) establishing vermi composting pit/bins. The vermi composting require little more care.

The following aspects have to be taken into consideration while planning a vermi composting programme.

i) The Vermi composting plant should be protected from flies, ants etc., by providing a metal net covering.
ii) Extreme wet and dry conditions will harm the worms and care should be taken to control extreme temperature by sprinkling water or putting a wet gunny bag above the plant especially during summer season.
iii) The Composting plant will not cause any smell, odour, or any unhygienic atmosphere, so it can be placed inside the house possibly in work area or even in a corner of the kitchen.

Table. 2

Design and Operational Specifications of Vermi composting Process

No	Aspects	Preferable standards and specifications
1	MSW characteristics	Any organic waste which are not appreciably oily, spicy, salty or hard and that do not have excessive acidity and alkalinity
2	MSW Particle size	Between 25 – 50 mm for optimum results
3	Worms	*Eudrillus eugineae* (50-100 no per kg of organic waste)
4	C/N Ratio	30:1 (preferred). Brown matter (wood products, saw dust, paper etc) is rich in carbon and green matter (food scraps, leaves etc) in nitrogen. Over abundance of greens generates ammonia. Correction is by application of brown matter.
5	pH	Slightly alkaline state preferable. Correction by adding small dose of calcium carbonate.
6	Temperature	20 – 30°C
7	Moisture content	40-55% preferable; cover the tank with wet sack and sprinkle water as required
8	Base layer	Coconut husk of one or two layers with cow-dung powder (~30 kg for 4m x 1m x 0.5m size tank)
9	Placing MSW	Waste layer thickness in the tank to be < 15 cm at a time; introduce fresh waste at consecutive portion of the tank on successive days
10	Blending	Sprinkle cow-dung powder alongwith waste
11	Aeration	Regular removal of the composted material, adding holes to the bin, or using a continuous-flow bin.
12	Physical protection	Wire mesh protection from mouse, ants and other pests; avoid exposure to direct sun light or rainfall.
13	Leachate collection	500 litre leachate collection tank for 250 kg/day plant
14	Area requirement	Tank size of 4m x 1m x 0.5m for waste input of 10 kg/day of semi decomposed waste

Source: Varma, A.K, 2009

3. BIOMETHANATION

Biogas is a mixture of gases composed of methane (CH_4) 40 - 70 % by volume, carbon dioxide (CO_2) 30 – 60 % by volume other gases 1 – 5 % by volume including hydrogen (H_2) 0-1 % by volume and hydrogen sulphide (H_2S) 0 - 3 % by volume. It originates from bacteria in the process of bio-degradation of organic material under anaerobic (without air) condition. The natural generation of biogas is an important part of the biochemical carbon cycle.

Methanogens (methane producing bacteria) are the last link in a chain of microorganisms, which degrade organic material and return the decomposition products to the environment. In this process, biogas is generated, which is a source of renewable energy.

As is the case with any pure gas, the characteristic properties of biogas are pressure and temperature dependency. It is also affected by moisture content. Well-functioning biogas systems can yield a whole range of benefits for their users, the society and the environment in general.

Biogas technology can substantially contribute to energy conservation and development, if the economic viability and social acceptance of biogas technology are favorable.

(i) Anaerobic Processing

Anaerobic processing of organic material is a two-stage process, where large organic polymers are fermented into short-chain volatile fatty acids. These acids are then converted into methane and carbon dioxide

Both the organic polymers fermentation process and acid conversion occur at the same time, in a single-phase system. The separation of the acid-producing (acidogenic) bacteria from the methane producing (methanogenic) bacteria results in a two-phase system.

The main feature of anaerobic treatment is the concurrent waste stabilization and production of methane gas, which is an energy source. The retention time for solid material in an anaerobic process can range from a few days to several weeks, depending upon the chemical characteristics of solid material and the design of the biogasification system (e.g., single stage, two-stage, multi-stage, wet or dry, temperature and pH control).

In the absence of oxygen, anaerobic bacteria decompose organic matter as follows:

$$\text{Organic matter + anaerobic bacteria} \longrightarrow CH_4 + CO_2 + H_2S + NH_3 \text{ + other end products + energy}$$

The conditions for biogasification need to be anaerobic, for which a totally enclosed process vessel is required. Although this necessitates a higher level of technology than compared to composting, it allows a greater control over the process itself and the emission of noxious odours. Greater process control, especially of temperature, allows a reduction in treatment time, when compared to composting. Since a biogas plant is usually vertical, it also required less area than a composting plant.Design and operational specifications of Biomethanation process is given in Table.3

(ii) Factors affecting biogasification

Similar to the composting process, a number of environmental factors influence biogasification some of which are listed below:

- **Temperature**: A temperature range of about 25 – 40°C (mesophilic) is generally optimal. It can be achieved without additional heating, thus being very economical. In some cases, additional energy input is provided to increase temperature to 50 – 60°C (thermophilic range) for greater gas production. Often digesters are constructed below ground to conserve heat.

Table. 3

Design and Operational Specifications of Biomethanation Process

No	Aspects	Preferable standards and specifications
1.	MSW characteristics	Sorted organic fraction only; Higher the putrescibility, better is the gas yield; Fibrous organic matter is undesirable as the anaerobic micro-organisms do not break down woody molecules such as lignin
2.	MSW Particle size	Shredded, minced and pulped particles increase the surface area for microbes to act and increase the speed of digestion.
3.	C/N Ratio	25-30 (preferable)
4.	Seeding	High gestation period is typical of anaerobic bacteria, hence seeding the digesters with sewage sludge or cattle slurry reduces reaction time and improves efficiency.
5.	Moisture content	>50%; Implications on feed, gas production, system type, system efficiency.
6.	Process environment	Absence of gaseous oxygen; anaerobes access oxygen from sources other than surrounding air, such as organic material.
7.	Mixing/turning	Every four or five days, until the temperature drops from about 66 – 60°C to about 38°C or less. Alternate days under typical operating conditions.
8.	Temperature	*Mesophilic* bacteria act optimally around 37°-41°C or at ambient temperatures between 20°- 45°C. *Thermophilic* bacteria act optimally around 50°- 52° and at elevated temperatures up to 70°C. Mesophiles are more tolerant to changes in environmental conditions and hence more stable, but thermophiles act faster.
9.	Solids content	High-solids with a TSS concentration greater than ~20% or Low-solids with a TSS concentration less than ~15%.
10.	pH control	Acidogenic bacteria through the production of acids reduce the pH of the tank. Methanogenic bacteria operate in a stable pH range and temperature.
11.	Digestion system stage	Single-stage system enables all the biological reactions in a single sealed reactor, hence different species will be in direct competition with each other.
12.	Residence time	For single-stage thermophilic digester, the residence time is around 14 days. For two-stage mesophilic digester, it varies between 15 and 40 days.
13.	Gas cleaning	Removal of hydrogen sulphide by scrubbing of biogas or by adding ferric chloride $FeCl_3$ to the digestion tanks.
14.	Dewatered digestate management	Aerobic composting for materials containing lignin and maturation for breaking down the ammonia into nitrates.
15.	Effluent water	Oxidation based treatment to bring down the elevated BOD and COD and curb the pollution potential.
16.	Degree of decomposition	Determine by COD test or from Respiratory Quotient (RQ).
17.	Post treatment care	Facility for effluent (leachate) recycling and treatment and sanitary landfill of rejects (inert materials, sludge from ETP)
18.	Nutrient recovery	4.0 - 4.5 kg N per ton; 0.5 - 1 kg P per ton; 2.5 - 3 kg K pr ton
19.	Product recovery	Biogas; 30% fibres and 50-65% fluids

Source: Varma, A.K, 2008

- **pH and alkalinity**: pH close to neutral, i.e., 7, is optimum. At lower pH values (below 5.5), some bacterial activities are inhibited. Excess loading and presence of toxic materials will lower pH levels to below 6.5 and can cause difficulties. When pH levels are too low, stopping the loading of the digester and/or use of time is recommended. The presence of alkalinity between 2500 and 5000 mg/L will provide good buffering against excessive pH changes.

- **Nutrient concentration**: An ideal C:N ratio of 25:1 is to be maintained in any compound to grow and multiply. Too much nitrogen, however, can inhibit methanogenic activity. If the C: N ratio is high, then gas production can be enhanced by adding nitrogen, and if the C: N ratio is low, it can be increased by adding carbon, i.e., adding chicken manure, etc., which reduces the possibility of toxicity.

- **Effect of toxins:** The main issue facing the biogas plants is the presence of toxic substance. Chlorinated hydrocarbons, such as chloroforms and other organic solvents, are particularly toxic to biogas digestion.

(iii) Types of Digesters

The operation and physical facilities for anaerobic digestion in single-stage digester (standard rate and high rate) and two-stage digester, which generally operate in a mesophilic range, i.e., between 30 and 38°C is given below:

***Standard rate single-stage digester**:* In a single-stage digester, the untreated waste sludge is directly added to the zone, where the sludge is actively digested and the gas is being released. The sludge is heated by means of an external heat exchanger. As the gas rises to the surface, it lifts sludge particles and other minerals such as grease oil and fats, ultimately giving rise to the formation of scum layer. As a result of digestion, the sludges stratify by forming a supernatant layer above the digesting sludge and become more mineralized, i.e., the percentage of fixed solid increases. Due to stratification and lack of mixing, the standard rate process is used principally for small installations. Detention time for standard rate processes vary from 30 to 60 days.

High rate single-stage digester: The single-stage high rate digester differs from the single-stage standard rate digester in that the solid-loading rate is much greater. The sludge is mixed intimately by gas recirculation, mechanical mixing, pumping or draft tube mixer and heated to achieve optimum digestion rates.

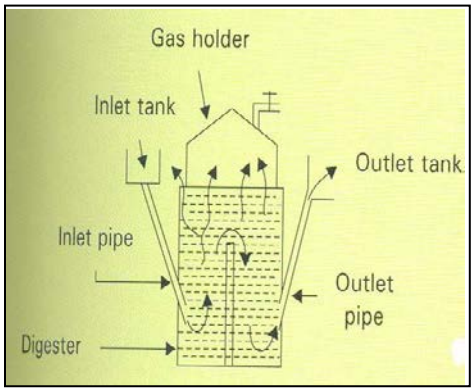
Two-stage digester: The combination of the two digesters, mentioned above, is known as a two-stage digester. The first stage digester is a high rate complete mix digester used for digestion, mixing and heating of waste sludge, while the primary function of a second stage is to separate the digested solid from the supernatant liquor, and in the process, additional digestion and gas production may occur. The tanks are made identical, in which case either one may be the primary digester. They may have fixed roofs or floating covers along with gasholder facility.

(iv) Biogas Plants in India

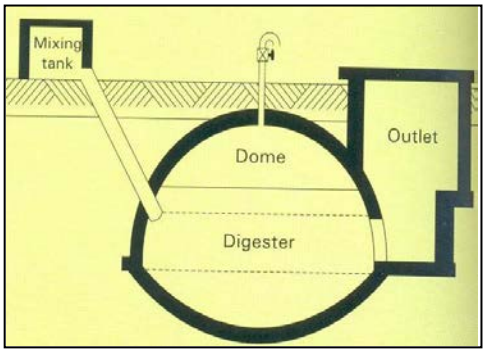
In India, the dissemination of large-scale biogas plants in the mid-seventies**,** and the process has become consolidated with the advent of the National Project on Biogas Development (NPBD), initiated by the then Ministry of Non-Conventional Energy Sources (http://mnes.nic.in)in 1981.

There are various biogas plant models approved by NPDB for implementation. All these models are based on the basic designs available: floating metal drum type, fixed masonry dome type, and FLEXI, a portable model made of rubberized nylon fabric, which has been approved for promotion in hilly and other terrains. Some of the NPDB approved models are as follows:

KVIC floating drum: Based on Gramalakshmi III, the first workable prototype of a biogas plant model– created by Jashbhai Patel, a Gandhian worker in the early 1950s – Khadi and Village Industries Commission (KVIC) developed this model in the early 1960s. This model has an underground cylindrical digester with inlet and outlet connections at the bottom on either side of a masonry wall. An inverted metal drum, which serves as the gasholder, rests on a wedge type support on top of the digester and, as the gas begins to accumulate, the drum starts rising in height. The weight of the drum applies pressure on the gas to make it pass through the pipeline to the point of use. As the gas flows out, the drum gradually moves down. Due to this smooth two-way motions, the gas remains at constant pressure, which ensures efficient use of gas.



Deenbandhu: Action for Food Production (AFPRO), a voluntary organization based in New Delhi, developed this model in 1984. Deenbandhu has been the most significant development in the entire biogas programme of India as the cost of the plant was nearly 50% less than that of the KVIC plant, and this brought the biogas technology within the reach of even the poorer sections of the population. The cost reduction was achieved by minimizing the surface area through joining the segments of two spheres of different diameters at their bases. This structure acts as a digester, and pressure is exerted on the slurry, which is pushed into a displacement chamber. The brick masonry dome, which is fixed, requires skilled workmanship and quality material to ensure no leakage.



Pragati: The United Socio-Economic Development and Research Programme (UNDARP), a Pune-based non-governmental organization, developed this model, which is a combination of KVIC and Deenbandhu designs. In this model, the lower part of the digester is semi-spherical in shape with a conical bottom. However, instead of a fixed dome, it has a floating drum acting as gas storage chamber. The spread of Pragati model has been confined mainly to the state of Maharashtra.

KVIC plant with ferro-cement digester: The Structural Engineering Research Centre, Ghaziabad, has developed the ferro-cement digester design in order to overcome the problems encountered in construction of traditional models of biogas plants. In this digester, layers of thin steel wire mesh, distributed throughout, are impregnated with rich mortar. Ferro-cement (i.e., concrete made of welded mesh, sand and cement) as a building material offers several advantages like 10 to 15% reduction in cost over KVIC digesters, usage of locally available material, less labour and little or no maintenance.

KVIC plant with fiber reinforced plastic (FRP) gasholder: FRP is used in place of metal in the floating drum gasholder. Contact Moulding Process, a technique of moulding without the application of external pressure, is adopted to manufacture the FRP. It employs one of the less expensive types of moulds, resulting in lowering the cost of the plant. The major advantage of FRP is its resistance to corrosion, which saves the recurring expenditure on painting the drum.

FLEXI: Developed by Swastik Rubber Products Ltd., Pune, is a portable model in which the digester is made of rubberized nylon fabric. The model is particularly suitable for hilly areas, where high transportation cost of construction materials, such as cement and bricks substantially increases the cost of installing the regular type of biogas plants.

(v) Components of biogas plant

A typical biogas plant has the following components:

- A digester in which the slurry (e.g., dung mixed with water) is fermented;
- An inlet tank used to mix the feed and let it into the digester;
- A gas holder/dome in which the generated gas is collected;
- An outlet tank to remove the spent slurry;
- Distribution pipeline(s) to carry the gas into the kitchen; and
- A manure pit, where the spent slurry is stored.

The compost produced and slurry from biogas plants is often used as a soil amendment in a variety of applications, after ascertaining the quality of the product. Since the product is used for a variety of purposes, contaminants in the compost could be detrimental to the environment. This is minimized through simple treatment procedures (i.e., waste segregation, proper turning and sufficient composting time).

4.0 INCINERATION TECHNOLOGY

Incineration is a chemical reaction in which carbon, hydrogen and other elements in the waste mix with oxygen in the combustion zone and generates heat. The air requirements for combustion of solid

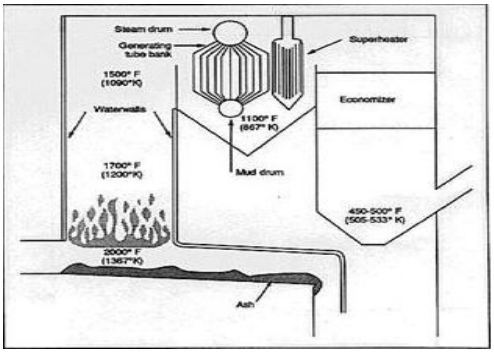
wastes are considerable. For example, approximately 5000 kg of air is required for each tonne of solid wastes burned. Usually, excess air is supplied to the incinerator to ensure complete mixing and combustion and to regulate operating temperature and control emissions. Excess air requirements, however, differ with moisture content of waste, heating values and the type of combustion technology employed. The principal gas products of combustion are carbon dioxide, water, oxygen and oxides of nitrogen.

Many incinerators are designed to operate in the combustion zone of 900 – 1100°C. This temperature is selected to ensure good combustion, complete elimination of odours and protection of the walls in the incinerator. Incinerator systems are designed to maximize waste burn out and heat output, while minimizing emissions by balancing the oxygen (air) and the three “Ts”, i.e., time, temperature and turbulence. Complete incineration of solid wastes produces virtually an inert residue, which constitutes about 10% of the initial weight and this residue is generally land filled.

The incineration facility along with combustion of waste emits air pollutants (i.e., fine particulate and toxic gases), thus leading to environmental concern. Other concerns relating to incineration include the disposal of the liquid wastes from floor drainage; quench water, scrubber effluents and the problem of ash disposal in landfills because of heavy metal residues. Design and operational specifications for MSW incineration is given in Table.4

The two most widely used and technically proven incineration technologies are Mass-burning incineration and Modular incineration.

(i) Mass-burning System



A mass-burn facility typically consists of a reciprocating grate combustion system and a refractory-lined, water-walled steam generator. Mass-burn systems generally consist of either two or three incineration units ranging in capacity from 50 to 1,000 tonnes per day. These facilities can accept refuse that has undergone little preprocessing other than the removal of oversiz ed items. Mass-burn facilities today generate a higher quality of steam (i.e., pressure and temperature), which is then passed through a turbine generator to produce electricity or through an extraction turbine to generate electricity as well as provide process steam for heating or other purposes.

(ii) Modular Incineration

Modular incinerator units are usually prefabricated units with relatively small capacities between 5 and 120 tonnes of solid waste per day. Typical facilities have between 1 and 4 units with a total plant capacity of about 15 to 400 tonnes per day. The majority of modular units produce steam as the sole energy product. Due to their small capacity, modular incinerators are generally used in small communities or for commercial and industrial operations. The prefabricated design gives modular facilities the advantage of a shorter construction time. Modular incinerators employ a different process from that of mass-burn incinerators, typically involving two combustion chambers, and combustion is typically achieved in two stages. In general, modular incineration systems are a suitable alternative and may, for smaller-sized facilities, be more cost-effective than other incinerators. The benefit of

incineration is a substantial reduction in the weight and volume of waste, and generation of revenue from energy production known as “waste-to-energy” (WTE), which can partially offset the cost of incineration. Most of the MSW incineration currently practice energy recovery in the form of steam, which is used either to drive a turbine to generate electricity or directly for heating or cooling. The three basic types of waste-to energy incineration are:

(i) Generation of electricity

(ii) Steam generation:

(iii) Co-generation

The major risks of incinerators are the potential emission of contaminants into the air through exhaust stack or into the water through ash leachate.

Table. 4

Design and Operational Specifications for MSW Incineration

No	Aspects	Preferable standards and specifications
1.	MSW characteristics	MSW with calorific value as high as possible; Volatile matter >40%; Fixed carbon <15%; Total inert <35%
2.	Moisture content	As minimum as possible; <45%
3.	Calorific value	As high as possible; >1200 kcal/kg
4.	Residence time & Operating temperature	At least 1 sec for flue gas at not less than 980°C in combustion zone
5.	Stack- Particulates	Not greater than 1.8 mg/m^3
6.	Stack- CO	Outlet concentration, not greater than 50 ppm (8-hr average)
7.	Stack HCl_2	Less than 4.5 g/hr
8.	Stack- SO_2	Not greater than 30 ppm (24-hr daily average)
9.	Stack- NO_x	Not greater than 30 ppm (24-hr daily average)
10.	Stack- Temperature	Flue gas temperature to be more than 150°C
11.	Dioxin or furan	0.2 ng/dry m^3 corrected to 7% oxygen
12.	Opacity	No emission having average opacity of 10% or more for any consecutive 6-minute period
13.	Noise	As per Pollution Control Board norms
14.	Pollution control	Use of scrubber, bag house, ESP, noise screens, silencers
15.	Monitoring- Emission	Online instrumentation for oxygen, plume opacity, SO_2, HCl, NO_x, CO, CO_2, Temperature and combustion index.
16.	Monitoring-Operation	Online instrumentation for steam pressure and flow, auxiliary fuel, ESP, fabric filters, gaseous contaminant emission control devices.
17.	Stack height	$H=14Q^{0.3}$ (Q is emission rate of SO_2 in kg/hr)
18.	Residue management	Bottom and fly ash to be reused to the maximum extent and the balance to be disposed of in a double-liner sanitary landfill.
19.	Nutrient recovery	Nil
20.	Recovery	15-25% bottom ash (including clinker, grit, glass), 3% metals
21.	Residuals	3% fly ash (including flue gas residues)

Source: Varma,A.K, 2008

5. PELLETIZATION / REFUSE DERIVED FUEL (RDF) SYSTEM

It is basically a processing method for mixed MSW, which can be very effective in preparing an enriched fuel feed for thermal processes like incineration or for use in industrial furnaces (Chantland, 2006).RDF consists largely of organic components of municipal waste such as plastics and biodegradable waste compressed into pellets, brickets or logs.RDF systems have two basic components: RDF production and RDF incineration.

RDF production facilities make RDF in various forms through material separation, size reduction and pelletizing. RDF production plants characteristically have an indoor tipping floor. The waste in an RDF plant is typically fed onto a conveyor, which is either below grade or hopper fed. In some plants, the loader doing the feeding will separate corrugated and bulky items like carpets. On the conveyor, the waste travels through a number of processing stages, usually beginning with magnetic separation. The processing steps are tailored to the desired products, and typically include one or more screening stages, using trommel or vibrating screens, shredding or hammer milling of waste with additional screening steps, pelletizing or baling of burnable wastes and depending on the local recycling markets and the design of the facility, a manual separation line. (Fig.2)

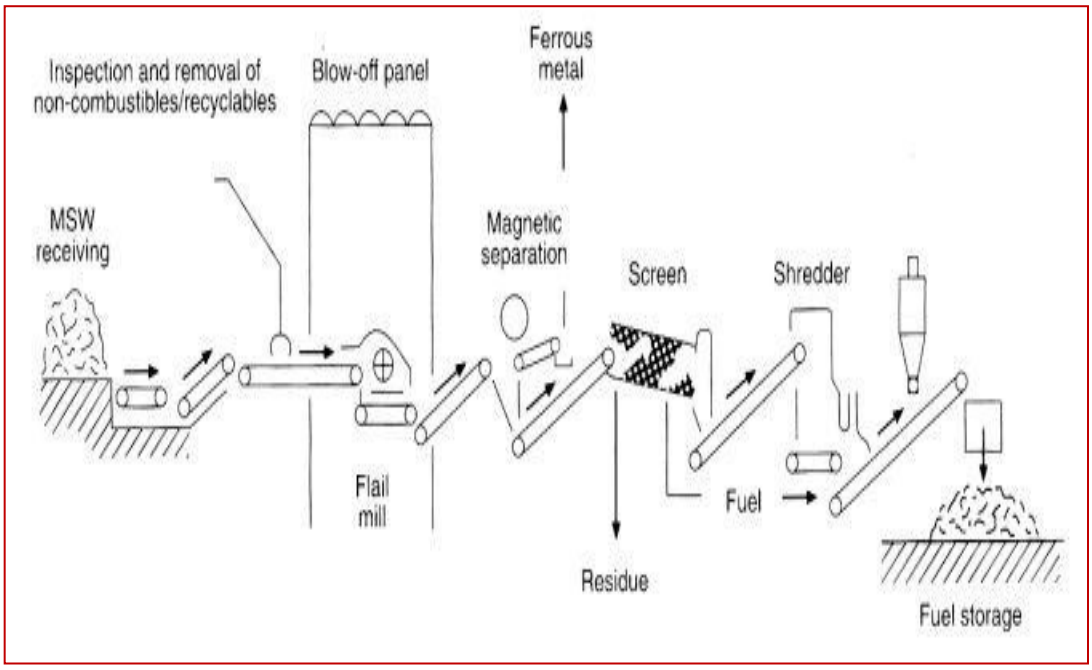


Fig. 2: Typical Simplified RDF Facility

There are two primary types of systems in operation, and they are:

i. **Shred-and-burn systems**: Shred-and-burn systems are the simplest form of RDF production. The process typically consists of shredding the MSW to the desired particle size that allows effective feeding to the combustor and magnetic removal of ferrous metal, with the remaining portion delivered to the combustor. There is no attempt to remove other non-combustible materials in the MSW before combustion. This, in essence, is a system with minimal processing and removal of non-combustibles.

ii. **Simplified process systems**: This is a system that removes a significant portion of the non-combustibles. A simplified process system involves processing the MSW to produce an RDF with a significant portion of the non-combustibles removed before combustion. The MSW process removes more than 85% of the ferrous metals, a significant percentage of the remaining non-combustible (i.e., glass, nonferrous metals, dirt, sand, etc) and shreds the material to a nominal particle top size of 10 to 15 cm to allow effective firing in the combustion unit.

Depending on the type of combustor to be used, a significant degree of separation can be achieved to produce a high-quality RDF (i.e., low ash), which typically results in the loss of a higher percentage of combustibles when compared to systems that can produce a low-quality fuel (i.e., slightly higher ash content) for firing in a specially designed combustor. These types of systems recover over 95% of the combustibles in the fuel fraction.

The RDF can be used alongside traditional sources of fuel in coal power plants, cement kiln industry, plasma arc gasification modules, pyrolysis plants, etc. RDF is capable of being combusted cleanly and can provide a funding source where unused carbon credits are sold on the open market via a carbon exchange.

6. PYROLYSIS AND GASIFICATION

„Pyrolysis and Gasification" is a process that converts carbonaceous materials, such as biomass into carbon monoxide and hydrogen by reacting the raw material at high temperatures with a controlled amount of oxygen (Middleton, 2005; Marshall & Morris, 2006; Varma AK, 2008) The resulting gas mixture is called synthesis gas or syngas and is a good fuel. Gasification is a method for extracting energy from different types of organic materials. The advantage of gasification is that using the syngas is more efficient than direct combustion of the original fuel. Gasification can also be done with materials that are not otherwise useful fuel, such as biomass or organic waste. It is an important technology for renewable energy.

7. PLASMA PYROLYSIS

Plasma pyrolysis or Plasma gasification is a waste treatment technology that gasifies matter in an oxygen-starved environment to decompose waste materials into its basic molecular structure (Williams & Nguyen, 2003; Varma A K, 2008). It uses high electrical energy and high temperature created by an electric arc gasifier and does not combust the waste as incinerators do. This arc breaks down waste primarily into elemental gas and solid waste (slag) in a device called plasma converter.

The process has been intended to be a net generator of electricity, depending upon composition of input wastes, and to reduce the volume of wastes being sent to landfill sites. High voltage and high current electricity is passed between two electrodes placed apart, creating an electrical arc where temperatures as high as 13,871^{0}C are reached. At this temperature most types of waste are broken into basic elemental components in a gaseous form and complex molecules are separated into individual atoms. Depending on the input waste (plastics tend to be high in hydrogen and carbon), gas from the plasma containment can be removed as Syngas, and may be refined into various fuels at a later stage. Dioxin emissions are possible from plasma arcs when chlorine is present although the extremely high temperature at which plasma gasification operates minimizes the possibility. Process gas clean up can

be necessary when gasifying waste streams such as municipal waste streams known to contain heavy metals, chlorine/fluorine, sulphur, etc.

Air Emission and its Control

The operation of the combustion process plays an important role in the formation of pollutants, which are carbon monoxide, NO_x (oxides of nitrogen), hydrocarbons and other volatile organic compounds. It also produces gaseous stream containing dust, acid gases (HCl, SO_x, HF), heavy metals and traces of dioxins (McDougall et al., 2001).

The majority of modern incinerators, however, produce less particulate and gaseous pollutants than their predecessors. The various gaseous pollutants formed due to incineration processes are Car bon dioxide (CO_2),Carbon monoxide (CO), Sulphur oxides (SO_x), Nitrogen oxides (NO_x), Particulates, Hydrochloric acid (HCl), Hydrogen fluoride (HF), Heavy metals (Hg, Cd, Pb, Zn, Cu, Ni, Cr), Dioxins and furans.

There are many technologies employed to carry out the necessary flue gas cleaning such as

i. Electrostatic precipitators (ESP)

ii. Fabric filters and

iii. Scrubbers.

Apart from air pollution, there are other environmental concerns related to incineration like water pollution, land-retained pollution, residue disposal, noise pollution, aesthetic impact, etc.

8. RECYCLING PROGRAMMES FOR SOLID WASTES

Recycling is one of the fundamental parts of the waste management plan. Recycling has a lot of direct significance for the society such as (i) Economic significance which includes cost reduction, employment generation, energy saving, reduced health care costs etc (ii) Environmental and health significance such as improved environment, natural resources conservation etc., and (iii) Social significance. The recycling of waste will increase the economic value of the waste and will reduce quantum of waste to be disposed.

(i) Processing Equipment for Recycling

Recycling involves a number of processing techniques and these processes require different equipments such as:

Shredder

A shredder is a mechanical device used to cut paper, plastics etc into small pieces. The main purpose of shredder is size reduction thereby reducing the volume and size of waste, as compared to its original form, and produce waste of uniform size. Or in other words shredding mechanism converts large sized wastes into smaller pieces.

The most frequently used shredding equipments are Hammer mill and Hydropulper. Due to high paper content in the waste from developed countries, a method developed by them is to hydropulp the waste and recover paper fibre from refuse. It is suitable for processing of paper waste only.

Selection of shredding equipment:

Following are the points to be noted before selecting shredding equipment

- The properties of materials before and after shredding
- Method of feeding shredders, provision of adequate shredder hood capacity
- Types of operation: continuous, intermittent
- Operational characteristics such as energy requirements, routine and specialized maintenance requirement, simplicity of operation, reliability, noise output, and air and water pollution control requirement
- Site consideration, including space and height, access, noise and related environmental limitations

Baling machine

Baling is compacting solid waste into blocks to reduce volume and to simplify handling. Solid waste baler is a machine used to compress recyclables into bundles to reduce volume. Balers are often used on newspaper, plastics and corrugated cardboard. They condense scraps and make it to a size for the most efficient handling and removal.

Balers are in a wide variety of configurations, sizes and costs based on the materials and the output demands. Their function is to transform volumes of waste into solid blocks of recyclable material, enabling recyclers to collect it easily and economically saving time, space and money.

Can densifiers

Can crushers are used to reduce the volume of aluminium and steel cans prior to transport.

Glass crushers

These are used to process glass fraction separated by colour and break it into small pieces. This crushed material is then called cullet, and can be reprocessed into new glass products.

Magnetic separators:

These are used to remove ferrous material from a mixture of materials.

Wood grinders

These are chippers and are used to shred large pieces of wood into chips that can be used as mulch or as fuel.

(ii) Commonly Recycled Materials and Processes

In this section, we will discuss some, commonly recycled materials, the technologies used to recycle them and their specific environmental and economic impacts.

Paper and Cardboard

Paper and cardboard form the second biggest component of domestic waste after organic waste, and contribute to about 13% of the total domestic solid waste. Paper recycling is one of the most profitable activities and is practiced extensively. It reduces the demand for wood and energy and helps solve littering problem in the city and around dumping site. It has an acceptable working condition and health risks are limited.

The paper industry is making a significant investment in manufacturing capacity for making paper and paper products with recycled content. Recovered paper is classified as newsprint, corrugated cardboard, mixed paper (including magazines, junk mail and cardboard), high-grade paper (white office paper, photocopying paper), and pulp substitute paper (usually mill scrap). Paper mills, the most common end users of recovered paper, use the material as a feedstock to manufacture recycled paper and paper products, such as newsprint, chipboard, craft linerboard, corrugating medium, roofing felt and tissue products. Shredded paper is used to make animal bedding, hydro mulch, moulded pulp products and cellulose insulation.

Glass

Glass is one of the most commonly recycled materials, and the market for post consumer glass has historically been steady. Glass generally accounts for 2.5% by weight of the total solid waste generated. Though it does not contribute to the environmental problem, glass does cause a serious problem of littering.

Recycling of broken glass reduces the risk of diseases caused by cuts and wounds. Glass recycling is a labour intensive process and provides employment opportunity. Glass is typically broken for size reduction or crushed and ultimately sold to glass manufacturers as furnace-ready cullet after metal caps, rings, labels, etc are removed (Fig.3). Glass manufacturers purchase glass for reprocessing into new, clear, green and brown glass jars and bottles. The market for recovered glass has been strong and stable for brown and clear containers. Green glass, however, is seldom used to package goods domestically, so fewer companies produce glass of this colour.

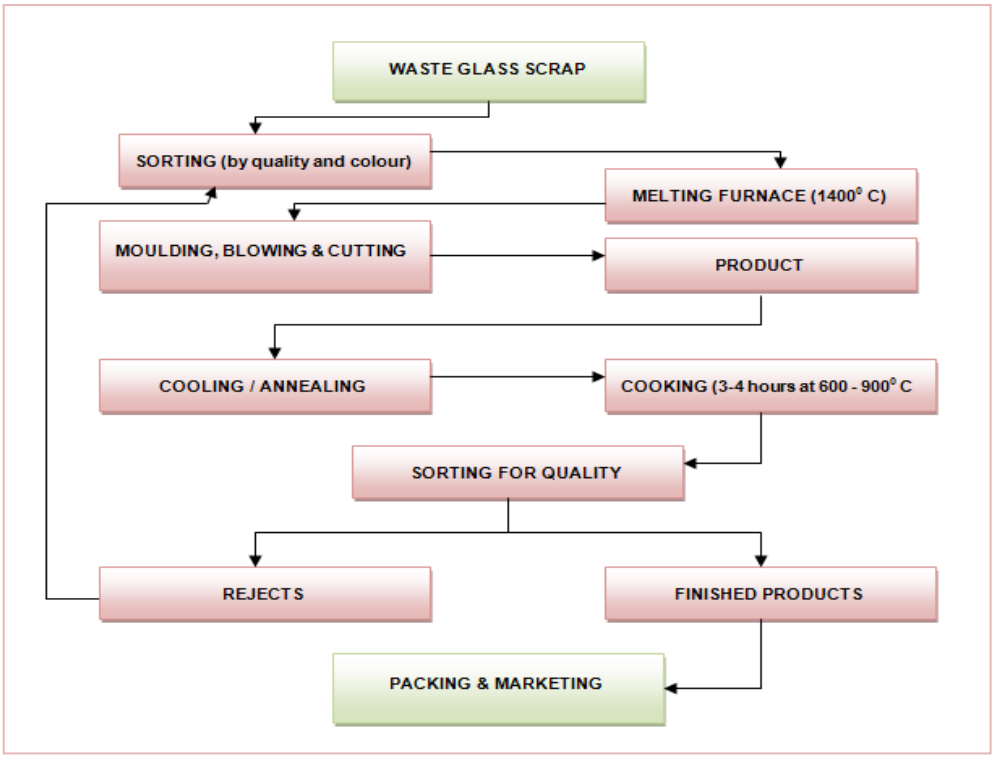


Fig. 3: Glass Processing (Semi – Mechanical)

Alternative markets for glass include art glass, sandblasting, and industrial windowpane glass and fiberglass insulation.

Metals

Ferrous metals like iron, steel, etc., and non-ferrous metals like aluminium, copper, zinc, lead, silver, etc., are some of the metals, which exist in the waste stream. On an average, metals account for 2% of total solid waste generated. Extraction of metals from natural ores depletes the mineral resources. Metals when dumped at landfill sites produce hazardous leachate with heavy metals in solution.

Using recycled metals substantially reduces operating costs of industries. Metal scrap is cheap and the energy consumption is lower when products are manufactured from scrap. The long standing track record makes ferrous and non-ferrous metal market among the most stable of all recyclable materials. Ferrous scrap includes household appliances, equipments, cans, and other iron and steel products. Non-ferrous scrap metals include aluminium, copper, lead, tin, etc.

Both ferrous and non-ferrous metals can be prepared for sale through some combination of processing by flattening, baling and shredding of the material. In some cases, processors melt the metal into ingots before selling it to end use markets. Several foundries and steel mills have begun or expanded recycling efforts, and steel mini-mills also appear to be increasing their use of recovered steel in regions which typically lack large mills.

Plastics

Plastic is posing serious littering problem in cities and around collection points and dumping sites. With an average 8% by weight of the total amount of domestic waste, plastic is one of the major constituents in waste stream. Plastic, when burned, contributes to green-house gases.

Volume reduction is done locally by flattering, baling or granulating, and sold either to converters, where the resins are turned into pellets, or directly to domestic or export end users for remanufacture into products such as bottles, carpet and carpet backing, flower pots and insulation material. Post-consumer plastic-resin recycling technology has developed more rapidly than technologies for any other recovered material in the last half century.

Only five to ten years ago post-consumer high-density polyethylene (HDPE) and polyethylene terephthalate (PET) plastics were vaguely considered recyclable. These two resins, especially HDPE milk jugs and bottles and clear PET plastics, now hold a stronger place in the market. End uses for recycled HDPE include non-food bottles, drums, toys, pipes, sheets and plastic pellet, and for PET include plastic fibres, injection moulding, non-food grade containers and chemicals. The recyclability of other resins, such as polystyrene, polyvinyl chloride, low-density polyethylene (LDPE), polypropylene and mixed plastic resins is making strides but much remains to be done. Table.5 illustrates the plastics that can be recycled.

Table.5

Common types of plastics that may be recycled

Sl. No	Chemical Name	Abbreviation	Typical uses
1	Polyethylene terephthalate	PETE	Soft drink bottles
2	High-density polyethylene	HDPE	Milk cartons
3	Polyvinyl Chloride	PVC	Food packaging, wire insulation & pipe
4	Low-density polyethylene	LDPE	Plastic film used for food wrapping, trash bags, grocery bags, and baby diapers
5	Polypropylene	PP	Automobile battery casings & bottle caps
6	Polystyrene	PS	Food packaging, foam cups & plates and eating utensils
7	Mixed plastic		Fence posts, benches & pallets

Source: Aarne vesilind, et al, 2004

In plastic processing, the primary steps are sorting by colour and quality and cutting and crushing the sorted material. The crushed product (granules) of plastic is melted, colour dyed and manually moulded into a cheaper product. The polyvinyl chloride plastic is blended with a specific colour dye in a mixing machine. The coloured material passes through an extruder machine to produce thick plastic strands. The strands are manually cut into lumps and these are used for manufacturing items either manually or mechanically.(See Fig.4)

In the manual process, the lumps are further chopped into smaller pieces and melted. The melted material is moulded into products such as shoe soles, toys and boxes. Machineries used in this process are electrically operated crusher, extruder, mixer and manually operated moulding machine (in which material is electrically heated at 359^{0}C).

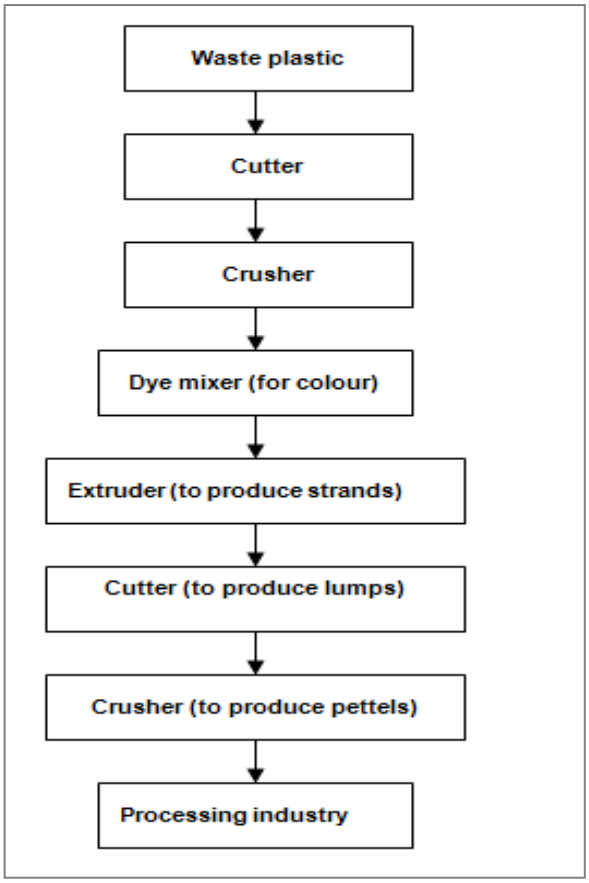


Fig.4 : Plastic Processing

Batteries and Tyres

Battery recycling is not only a response to market condition (i.e., price of lead) but also is important due to concern over the toxic compound including lead, cadmium and mercury present in many batteries. Like other materials, battery recycling depends largely on market conditions and requires consistent collection and processing.

Household batteries come in a variety of types including alkaline, carbon, zinc, silver, nickel, cadmium etc. Only those containing mercury and silver are marketed to end users, who extract metals. Automobiles use lead acid battery, which contains lead and sulphuric acid, both hazardous materials. Battery reprocessing includes breaking open the batteries, neutralizing the acid, chipping the container for recycling and smelling the lead to produce recyclable lead. Tyres represent a special challenge to solid waste recycling programme. The use of chipped or shredded tyres as source for fuel is growing. Electricity-generating facilities, pulp and paper mills and cement kilns are the most common processes using scrap tyres.Table.6 illustrates the advantages and drawbacks of recycling materials.

Table. 6
Important recycling materials: advantages and drawbacks

Material	Advantage	Drawbacks
Aluminum	• Aluminum has a high market value. • It can be easily recycled by shredding and melting. • It can be recycled indefinitely because it does not deteriorate from reprocessing. • Aluminum recycling requires significantly less energy than producing aluminum from ore.	• Separate collection is important. • Recycling is suitable only if a processing plant is available.
Batteries	• Recycling recovers valuable metals. • Recycling protects the environment from heavy metals such as lead, cadmium and mercury.	• Large variation in type and size of batteries requires specific recycling processes. • Older batteries have high heavy metal content
Concrete and demolition waste	• Demolition waste can be crushed to gravel and reused in road construction and landscaping.	• Machinery required for crushing is maintenance intensive. • Recycled waste is valuable only if there is a lack of other construction material.
Glass	• Glass has a moderate market value • It can be sorted into colours and melted. • Use of recycled glass saves energy compared with processing raw material. • Glass can be recycled indefinitely because it does not deteriorate from reprocessing.	• Broken glass can contaminate and eliminate opportunities for recycling.
Other metal	• Scrap metal has a high market value (especially steel, copper, silver and platinum) • It can be recycled indefinitely because it does not deteriorate from reprocessing.	• High-value metals (such as copper and silver) are incorporated in electronic devices, but extraction can cause severe environmental impacts.
Paper	• Paper can be easily recycled; however, quality deteriorates with each cycle. • Paper or cardboard from recycled paper requires less energy to produce	• Appropriate technologies with circular processes are required to protect the environment.
Polyethylene terephthalate (PET)	• PET can be recycled if segregated from other waste. • Reprocessing into granulate is very easy. • PET has a high market value if processing plants are available.	• More „downcyling" than recycling occurs because quality decreases with every processing cycle.
Other plastics	• Other plastics such as polyethylene or polyvinyl chloride, can be recycled but has less value on the market than PET; the value depends on recycling and manufacturing options in the vicinity.	• Recycling requires specific machinery
Electronic waste	• Electronic waste (such as computers or mobile phones) contains high value metals. • Electronic items can be dismantled, reused or recycled.	• Metals are often covered with polyvinyl chloride or resins, which are often smelted or burned, causing toxic emissions.

Source: World Bank, 2008

Electronics Waste or E waste

Electronics Waste or E waste is a collective name for discarded electronic devices that enter the waste stream or nearing the end of their "useful life". It consists of obsolete electronic devices such as computers, monitors and display devices, telecommunication devices such as cellular phones, calculators, audio and video devices, printers, scanners, copiers and fax machines besides household equipments such as refrigerators, air conditioners, televisions and washing machines.

The biggest concern with E-Waste is the presence of toxic materials such as lead, cadmium, mercury and arsenic, toxic flame-retardants, printer cartridge inks and toners that pose significant health risks. These components can contaminate soil, groundwater and air, as well as affect the workers of the recycling units and the community living around it. The huge range and complexity of component materials in e-products makes it difficult and expensive to dispose of or recycle them safely and at a profit.

Eco-designing of products, source reduction, close-loop recycling etc; are potential options to reduce the e-waste stream. Designers could ensure that the product is built for re-use, repair and/or upgradeability. Stress should be laid on use of less toxic, easily recoverable and recyclable materials which can be taken back for refurbishment, remanufacturing, disassembly and reuse. Recycling and reuse of materials are potential options to reduce e-waste. Recovery of metals, plastic, glass and other materials reduces the magnitude of e-waste. These options have a potential to conserve the energy and keep the environment free of toxic material that would otherwise have been released.

Indian E waste recycling system has been developed very organically, as a natural branching of the scrap industry which accepts scrap from many sources. In contrast to developed countries, where consumers pay a recycling fee, in India it is the waste collectors who pay consumers a positive price for their obsolete appliances. The small collectors in turn sell their collections to traders who aggregate and sort different kinds of waste and then sell it to recyclers, who recover the metals. The entire e waste recycling industry in India is based on a network existing among scrap collectors, traders and recyclers, each adding value, and creating jobs, at every point in the chain. The main incentive for the players is financial profit, not environmental or social awareness. Nevertheless, these trade and recycling alliances provide employment to many groups of people.

Extended producer responsibility (EPR) principle has been one of the main driving forces while regulatory frameworks for the environmental and economic management of e-wastes. EPR is the principle in which all the actors along the product chain share responsibility for the lifecycle environmental impacts of the whole product system. *Manufacturers* can reduce the life-cycle environmental impacts of their products through their influence on product design, material choices, manufacturing processes, product delivery, and product system support.

9. SANITARY LANDFILL

The term „landfill" is used to describe a unit operation for final disposal of „Municipal Solid Waste" on land and is a systematic disposal technique especially for the rejects after processing. This term encompasses other terms such as „secured landfill" and „engineered landfills" which are also sometimes applied to municipal solid waste (MSW) disposal units. Under the MSW rules vide Gazette Notification Number 648 extra ordinary under schedule II Sr. No. 6 and Schedule III requirements for sanitary landfill have been specified. Development and operation of SLF is an integral part of MSW processing. The remnants from processing and unusable waste have to be disposed off in SLF on daily basis.

Landfill is vital component of any well designed SWM system. It is the ultimate repository of all other SWM options. The overall approach to the development of the common sanitary landfill is formulated to satisfy the regulatory requirements of MoEF, CPHEEO guidelines with objectives of environmental protection.

(i) Landfill Design Criteria

Design considerations for sanitary landfill development are primarily guided by the characteristics of the proposed site and the guidelines framed by the Ministry of Environment and Forests, Government of India. Part II, Section 3, Sub-Section (ii), Rule 6(1), 6 (3) and 7 (2) of these guidelines indicate that the sanitary landfill shall comply with the following conditions:

- The minimum bottom liner specifications shall be a composite barrier having 1.5 mm High Density Polyethylene (HDPE) geomembrane overlying 900 mm of soil(clay/amended soil) having permeability coefficient not greater than 1 x 10^{-7} cm/sec. The surface below amended soil layer should be well compacted
- Waste shall be compacted adequately and provided with daily cover of minimum 10cm of soil inert debris
- Prior to commencement of monsoon, intermediate cover of thickness of about 45 cm has to be provided with proper compaction and grading to prevent infiltration during monsoon. Proper drainage berms shall be provided to divert runoff from the active cell of the landfill
- The final cover shall have a barrier layer comprising of 60 cm of clay/amended soil with permeability coefficient not greater than 1 x 10^{-7} cm/sec., on the top of the barrier soil layer there shall be a composite barrier having 1.5 mm High Density Polyethylene (HDPE) sheet. Over that there shall be a drainage layer of 15 cm and on the top of drainage layer there shall be a vegetative layer of 45 cm thick
- The post closure care of landfill site shall be conducted for at least fifteen years and long-term monitoring plan shall be prepared.

- In order to prevent the pollution problems storm water diversion drains, leachate collection and treatment system and preventive measures for runoff from landfill area entering any stream, lake, river or pond shall be provided
- Buffer zone around the landfill site and a vegetative cover over the completed site shall be provided
- Leachate monitoring well has to be provided.

Preparation of Liner System

- Liner system within a landfill involves prevention of percolation of leachate from waste in landfill to the sub-soil by a suitable protective system (liner system), which comprises of a combination of barrier material such as natural clay and amended soil and a flexible geo-membrane. The liner system will be of low permeability and will be robust, durable and to resist the chemical attack, puncture, rupture etc.
- The liner system is designed in compliance with Municipal Solid Waste (Management and Handling) Rules 2000 and, will comprise, a 90cm thick compacted clay or amended soil of permeability not greater than $1x10^{-7}$, a HDPE geo-membrane liner of thickness 1.5mm and a drainage layer of 15cm thick granular material of permeability not greater than $1x10^{-2}$ cm/sec.
- *Preparation of Amended Soil Liner*. The permeability of local soil varies depending upon the soil condition.. To reduce the permeability to $1x10^{-7}$, the soil will be amended with bentonite, which is known to have permeability of the order 1×10^{-7} cm/sec.
- Based on the soil characteristics, it is recommended to maintain the soil and bentonite proportion as 80:20 and mix the additives on site, before it is placed at the base of the landfill site, as a barrier layer.
- After the preparation of the amended soil liner, the liner should be constructed in series of lifts each of 25cm compacted to about 15cm by four to five passes of sheep foot roller. The finished thickness of the liner should be 90 cm and the final permeability of the amended soil should also be checked for the desired permeability of 1×10^{-7}.
- *Geo-Membrane Liner:* Geo-membrane is relatively a thin sheet of flexible thermoplastic or thermopolymeric material. Because of their inherent impermeability, geo-membranes are proposed as barrier layer in landfill site. Even though geo-membranes are highly impermeable, their safety against manufacturing, installation, handling and other defects is essential criteria in design of liner system. The effectiveness of barrier layers basically depends on the hydraulic conductivity of the day / amended clay liner and density of geomembrane. The clay liner is effective only if it is compacted properly and geomembrane liner is effective only if it has a density or mass per unit area is sufficient enough against puncture.
- In order to strengthen the base to avoid any seepage of generated leachate, a layer of 1.5 mm thickness Geomembrane (HDPE liner) is laid over the clay liner. This liner is laid with the help of double wedge hot shoe welder to prevent leakage and testing is done for the same. The liner shall be anchored at the top of landfill side wall and side cutting beyond the stipulated area of the fill.

- Granular Soil Material with 6 mm stone aggregate. At the bottom of the liner, coarse sand would be spread. The thickness of the sand would be 300mm thick.

Settling Process in a Landfill

- **Primary consolidation**: During this stage, a substantial amount of settling occurs. This settlement is caused by the weight of the waste layers. (Fig. 5) The movement of trucks, bulldozers or mechanical compactors will also enhance this process. After this primary consolidation, or short-term deformation stage, aerobic degradation processes occur.
- **Secondary compression**: During this stage, the rate of settling is much lower than that in the primary consolidation stage, as the settling occurs through compression, which cannot be enhanced.
- **Decomposition:** During the degradation processes, organic material is converted into gas and leachate. The settling rate during this stage increases compared to the secondary compression stage and continues until all decomposable organic matter is degraded

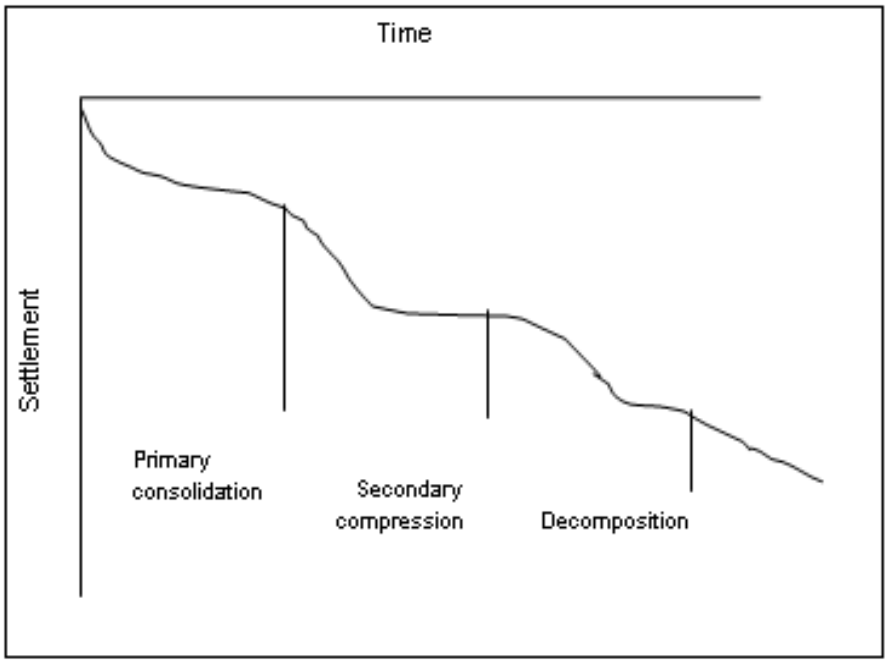


Fig. 5 : Settling process in a landfill

The microbial degradation process is the most important biological process occurring in a landfill. These processes induce changes in the chemical and physical environment within the waste body, which determines the quality of leachate and both the quality and quantity of landfill gas. Since, landfills mostly receive organic wastes microbial processes will dominate the stabilization of the waste and therefore govern landfill gas generation and leachate composition.

Soon after disposal, the predominant part of the wastes becomes anaerobic, and the bacteria will start degrading the solid organic carbon, eventually to produce carbon dioxide and methane. The biotic factors that affect methane formation in the landfill are pH, alkalinity, nutrients, temperature, oxygen and moisture content.

(ii) Leachate Formation

Leachate can pollute both groundwater and surface water. The degree of pollution will depend on local geology and hydrogeology, nature of waste and the proximity of susceptible receptors. The amount of leachate generated depends on:

- Water availability
- Landfill surface

condition • Refuse state

- Condition of surrounding strata

The major factor, i.e., water availability, is affected by precipitation, surface runoff, waste decomposition and liquid waste disposal. The water balance equation for landfill requires negative or zero ("Lo") so that no excess leachate is produced. This is calculated using the following formula.

$Lo = I - E - aW$

ie $I - E < aW$

where Lo = free leachate retained at site (equivalent to leachate production minus leachate leaving the site); I = total liquid input; E = evapotranspiration losses; a = absorption capacity of waste; and W = weight of waste disposed.

Common toxic components in leachate are ammonia and heavy metals, which can be hazardous even at low levels, if they accumulate in the food chain. The presence of ammoniacal nitrogen means that leachate often has to be treated off-site before being discharged to a sewer, since there is no natural bio-chemical path for its removal. The degree of groundwater contamination is affected by physical, chemical and biological factors. The best way to control leachate is through prevention, which should be integral to the site design. In most case, it is necessary to control liquid access, collection and treatment, all of which can be done using the following landfill liners.

(iii) Leachate Treatment

Concentrations of various substances occurring in leachate are too high to be discharged to surface water or into a sewer system. These concentrations, therefore, have to be reduced by removal, treatment or both. The various treatments of leachate include:

Leachate recirculation: It is one of the simplest forms of treatment. Recirculation of leachate reduces the hazardous nature of leachate and helps wet the waste, increasing its potential for biological degradation.

Biological treatment: This removes BOD, ammonia and suspended solids. Leachate from land fill waste can be readily degraded by biological means, due to high content of volatile fatty acids (VFAs). The common methods are aerated lagoons (i.e, special devices which enhance the aerobic processes of degradation of organic substances over the entire depth of the tank) and activated sludge process, which differs from aerated lagoons in that, discharged sludge is re-circulated and often leads to BOD and ammonia removal. While under conditions of low COD, rotating biological contractors (i.e, biomass is brought into contact with circular blades fixed to a common axle which is rotated) are very effective in removing ammonia. In an aerobic treatment system, complex organic molecules are fermented in filter. The common types are anaerobic filters, anaerobic lagoon and digesters.

Physiochemical treatment: After biological degradation, effluents still contain significant concentrations of different substances. Physiochemical treatment processes could be installed to improve the leachate effluent quality. Some of these processes are flocculation and precipitation. Separation of the floc from water takes place by sedimentation, adsorption and reverse osmosis.

Leachate and Landfill Gas

Leachate may contaminate the surrounding land and water; landfill gas can be toxic and lead to global warming and explosion leading to human catastrophe. The major factors, which affect the production of leachate and landfill gas are nature of waste, moisture content, pH, particle size and density, temperature etc.

Landfill gas contains a high percentage of methane due to the anaerobic decomposition of organic matter, which can be utilized as a source of energy. A typical landfill gas contains a number of components other than Methane such as Carbon dioxide, Oxygen and Nitrogen.

The basic elements of the leachate collection system (i.e., drain pipes, drainage layers, collections pipes, sumps etc) must be installed immediately above the liner, before any waste is deposited. Particular care must also be taken to prevent the drain and collection pipes from settling. During landfill operations, waste cells are covered with soil to avoid additional contact between waste and the environment. The soil layers have to be sufficiently permeable to allow downward leachate transport. Landfill gas is not extracted before completion, which includes construction of final cover of the waste body. Extraction wells (diameter 0.3 to 1.0m) may be constructed during or after operation.

(iv) Leachate Treatment

The major potential environmental impacts related to landfill leachate are pollution of groundwater and surface waters. Pollutants in MSW landfill leachate can be divided into four groups:

- Dissolved organic matter, quantified as Chemical Oxygen Demand (COD) or Total Organic Carbon (TOC), volatile fatty acids (that accumulate during the acid phase of the waste stabilization, Christensen and Kjeldsen, 1989) and more refractory compounds such as fulvic-like and humic-like compounds.
- Inorganic macro components: Calcium ($Ca2^+$), Magnesium ($Mg2^+$), Sodium (Na^+), Potassium (K^+), Ammonium ($NH4^+$), Iron ($Fe2^+$), Manganese ($Mn2^+$), Chloride (Cl^-), Sulfate ($SO42^-$) and Hydrogen Carbonate ($HCO3^-$).
- Heavy metals: Cadmium ($Cd2^+$), Chromium ($Cr3^+$), Copper ($Cu2^+$), Lead ($Pb2^+$), Nickel ($Ni\ 2^+$) and Zinc ($Zn2^+$).
- Xenobiotic organic compounds (XOCs) originating from household or industrial chemicals and present in relatively low concentrations (usually less than I mg/l of individual compounds). These compounds include among others a variety of aromatic hydrocarbons, phenols, chlorinated aliphatics, pesticides, and plastizers.

Other compounds may be found in leachate from landfills: for example, borate, sulfide, arsenate, selenate, barium, lithium, mercury, and cobalt. However, in general, these compounds are found in very low concentrations and are only of secondary importance. Leachate composition may also be characterized by different toxicological tests, which provide indirect information on the content of pollutants that may be harmful to a class of organisms. For designing of leachate treatment plant (LTP) we have taken into consideration the seasonal variations in quantity and quality of leachate.

Design aspects of Leachate treatment plant

The design of LTP varies depends upon the quantity, characteristics and the extend of treatment. An illustration of a treatment procedure adopted in Thiruvanathauram City Corporation is given below.(also see Fig. 6)

Screen Chamber: The leachate from compost and landfill are conveyed through pipes and brought to the screen chambers. It is better to provide two screen chambers: one in the landfill leachate line and another in the compost leachate line. Screen chambers are provided with SS basket screen and also a fixed inclined SS bar screen. The basket screen helps in retaining bigger sized particles, pieces of plastic, paper and wood material, rags and other large debris which would otherwise clog the pipe lines and damage the pumps. The screened matter is removed periodically and disposed off in the landfill. Bar screens provide additional screening for material which may escape the basket screens, especially during the cleaning operations. The screened leachate from both the lines will be then collected in the collection tank.

Collection Tank: The screened leachates from different points are collected in the collection tank. The quantity of flow and concentration of leachate effluent is not constant and varies with time and location. The purpose of collection tank is to dampen these variations or equalize the flow in terms of both quantity and concentrations. The equalized leachate is pumped at required flow rate to Upflow Anaerobic Sludge Blanket Digester (UASB). If there is no space constraint, then the leachate can be treated in an Anaerobic Lagoon.

Upflow Anaerobic Sludge Blanket Digester (UASB): UASB Digester maintains a high concentration of biomass through formation of highly settleable microbial aggregates. The wastewater flows upwards through a layer of sludge. At the top of the reactor phase, separation between gas, solids and liquid takes place due to baffles and launders. This anaerobic digester is completely covered and biogas generated can be collected and suitably utilized. Biogas capture and use are essential for pollution abatement and go a long way in Green House Gases mitigation. The BOD reduction efficiency of 90% can be achieved. The overflow from UASB can be collected in Anoxic Zone if needed.

Anoxic Zone: An anoxic zone is a portion after anaerobic digester, which is mixed with activated sludge but not aerated. The dissolved oxygen levels may be less than 1.0 mg/l but never reach 0.0 mg/l. This will enable the anaerobic microbe's to convert to aerobic at the earliest. The overflow from this zone is connected to aeration tank. Part of the sludge from anoxic tank / zone is sent to aeration tank to maintain MLSS.

Aeration Tank: The overflow from anoxic zone is connected to the aeration tank for further reduction of organic load. The wastewater containing residual organic matter is aerated in an aeration tank in which micro-organisms metabolize the suspended and soluble organic matter. The micro-organisms, which are responsible for the conversion of organic or the other matter in the wastewater to gases and cell tissues, are maintained in suspension within the liquid. Part of organic matter is synthesized into new cells and part is oxidized to CO^2 and water to derive energy. The new cells formed in the reaction are removed from the liquid stream in the form of a flocculent sludge in settling tank. A part of this settled biomass, described as activated sludge is returned to the aeration tank and the remaining forms waste or excess sludge. The BOD reduction efficiency in both the aeration tanks is about 80% each.

Settling Tank: The overflow from aeration tank is connected to settling tank. Here separation of

solids and liquid takes place.

Clarified Water Sump: The overflow from settling tank will be collected in clarified water sump. Then the clarified water will be passed through pressure sand filter and activated carbon filter and will be stored in treated water storage tank. For disinfection, sodium hypochloride is added.

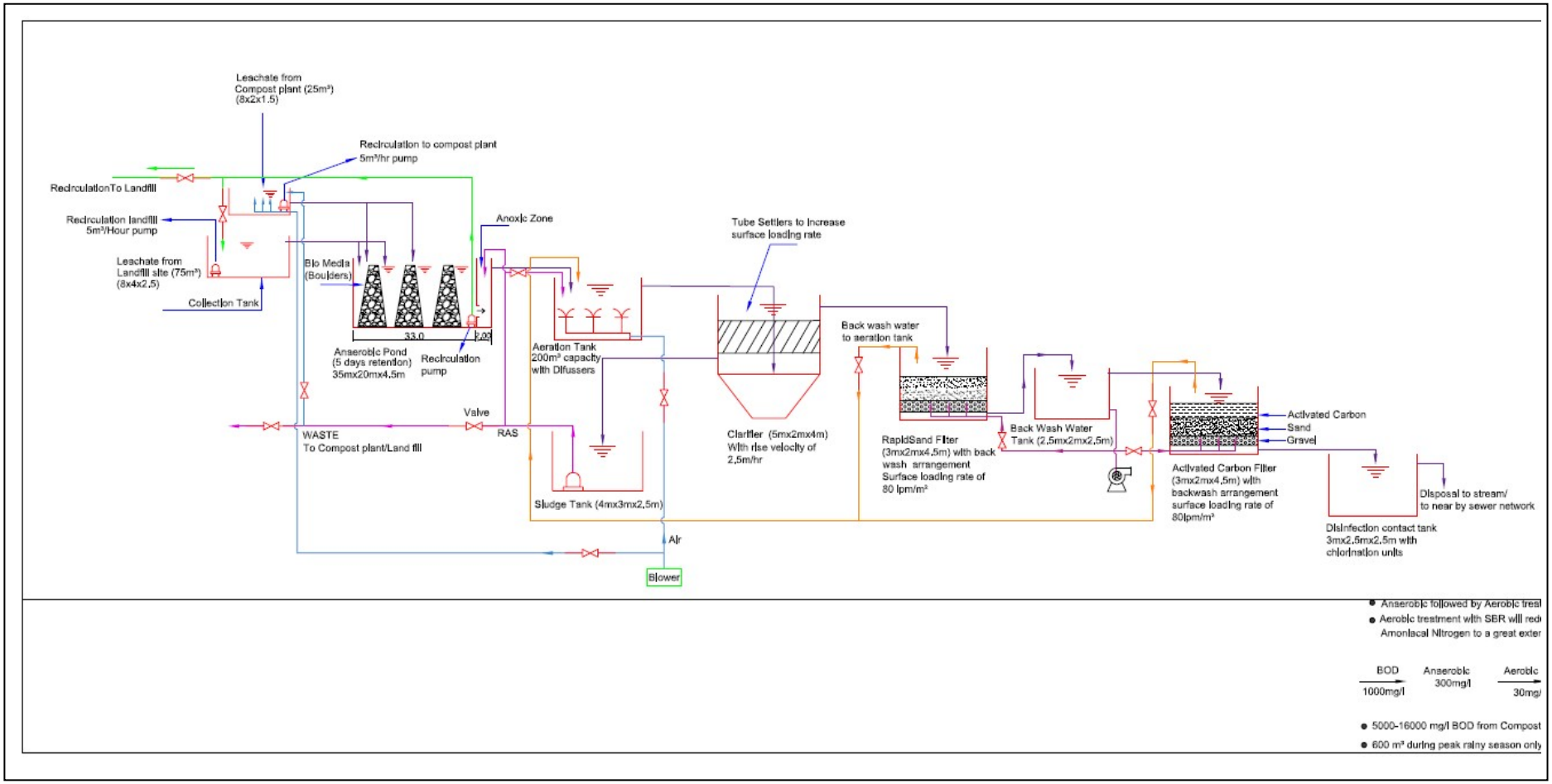
Treated Water Tank: The final treated effluent is stored in a treated water tank and can be used for irrigation purpose. Sampling will be done frequently to ascertain the quality of treated water.

(v) Monitoring

Leachate/gas: Monitoring of leachate/gas plays a vital role in the management of landfills. Data on the volume of leachate/gas and their composition are essential for proper control of leachate/gas generation and its treatment. Knowledge of the chemical composition of leachate/gas is also required to confirm that attenuation processes within the landfill are proceeding as expected. Various systems for monitoring the leachate level are in use, and are mostly based on pipes installed prior to land filling. Small bore perforated plastic pipes are relatively cheaper and easier to install, but have the disadvantage of getting damaged faster during infilling. Placing pipes within a column or tyres may however, offer some protection.

Groundwater: A continued groundwater-monitoring programme for confirming the integrity of the liner system is essential. During site preparation, a number of monitoring boreholes need to be provided around the site. The location, design and number of boreholes depend on the size of the landfill, proximity to an aquifer, geology of the site and types of wastes deposited. Installation of a double liner system can make the monitoring exercise more accurate and easier to perform. Water should be regularly flushed through the secondary leachate collection system. In case this water is polluted, the primary leachate barrier will be damaged, and if repair is not considered possible, the leachate collected must be transported to the leachate treatment facility.

Fig.6 : Typical Design of Leachate Treatment Plant



Source: Thiruvananthapuram Corporation

REFERENCES

Aarne vesilin P;William Worrel and Debra Reinhart,2004.Solid Waste Engineering

Benedict A.H, Epstein E and Alpert J, 1988. Composting Municipal Sludge- A Technology Assessment. Noyes Data Corporation. Park Ridge. NJ

Corey R.C, 1969. Principles and Practices of Incineration. Wiley-Interscience, New York.

CPCB (Central Pollution Control Board), 2000. Status of Municipal Solid Waste Generation, Collection, Treatment and Disposal in class I cities. CUPS/48/1999-2000- CPCB, Ministry of Environment and Forest, New Delhi.

CPHEEO, 2000. Manual on Municipal Solid Waste Management 1st Ed. Central Public Health and Environmental Engineering Organisation, Ministry of Urban Development, Government of India, NewDelhi.

Da Zhu, Asnani P.U, Chris Zurbrugg, Sebastian Anapolsky and Shyamala Mani, 2008. Improving Municipal Solid Waste Management in India, World Bank, Washington, D.C.

Diaz L.F, Savage G.M, Golueke C.G, 2002. Composting of Municipal Waste. In Tchobanoglous G and Kreith F (Ed.). Solid Waste Handbook. 2nd Ed. McGraw Hill, New York.

Marshall A. T and Morris J. M. 2006. A Watery Solution and Sustainable Energy Parks, Jl. CIWM. Pp. 22-23

Middleton Marc, 2005. Local recycler ignites Euro fuel market. Waste Management and Environment Media Pty Ltd.

Salvato J.A. 1992. Environmental Engineering and Sanitation. 4th Ed. Wiley. New York.

Tchobanoglous G. 2003. Solid Waste Management in Environmental Engineering (Ed. Salvato J.A., Nemerow N.L. and Agardy F.J). 5th Ed. John Wiley and Sons Inc. New Jersey.

UNEP, 1996. International Source Book Environmentally Sound Technologies for Municipal Solid Waste Management .6. IETC, Osaka/Shiga.

Varma Ajaykumar R, 2008., Technology Options for Treatment of Municipal Solid Waste with special reference to Kerala, Proceedings of Kerala Environment Congress, 2008.

Williams, Jenkins & Nguyen. 2003. Solid Waste Conversion: A review and database of current and emerging technologies. Spl. Rep. for California Integrated Waste Management Board, Dept. of Biological and Agricultural Engineering, University of California. IWM-C0172:23.

ANNEXURE – 1

WINDROW COMPOST PLANT DESIGN ASPECTS

Compost Pad (Plant)

Capacity and shape of plant

Capacity of the plant should be decided based on the quantity of garbage to be available and quantity processed per hour and number of hours the plant could run per day.

Bulk density of the garbage considered as 700Kg/cu.m. Assume the garbage reaching to the plant is 'x'MT. Then the volume will be x/0.7 cu.m.

Standard height of the garbage heap considered as 2.00m from floor level.

Area required for accommodating 'x'MT of garbage is x/0,7 X 2.00 Sq.M.= x/1.4sq.m.

Decomposition period of garbage is minimum 35 days.

Composting pad (windrow area) should be designed for accommodating minimum 40 days waste (with 5 days allowance)

35 to 40 percentage more area to be provided for accommodating processing machineries (3 numbers of trommels and conveyor belts etc.)

40 to 50 percentage free areas shall be provided for free movement of the turning equipments.

Considering that, the volume of fresh garbage will reduce by 35% after 35 days composting process, the corresponding reduction can be considered while designing the windrow area.

Circular or polygon shape is most convenient for handling and stacking the garbage.

Compost pad or Windrow floor

The windrow floor area should be provided with impermeable base. Such a base should be paved with impervious floor of 200mm, thick cement concrete (reinforced) over a 250 mm thick compacted earth and 150 mm thick PCC base having permeability coefficient less than 10^{-7} cm/sec.(reinforced concrete should be minimum M30 grade and PCC should be M15 grade).

Concrete floor should have adequate strength to bear dynamic load due to turning equipments on compost pad.

2% slop and lined drain to be provided for collecting leachate.

Necessary expansion joint should be provided on the floor slab and the joint shall be filled with Mastic Asphalt 20mm width.

Civil structure (covering of the compost pad)

The compost pad should be covered from the top with proper roof so as to enable 35 days of decomposition under roof to prevent wetting of the material from possible rainfall.

The civil structure should be designed with mixed design criteria of RCC and fabricated steel members.

Bottom part of the columns up to 3.5M. height should be with reinforced concrete for avoiding corrosion due the contact of garbage.

All RCC members are designed confirming to IS 456-2000 and accordingly M30 grade cement concrete with blended cement like Portland Slag Cement confirming IS 455. Unreinforced or plain cement concrete are M20 or M15. High yield strength deformed bars of corrosion resisting quality with a minimum guaranteed yield stress of 500 MPa may be used.

Structural steel works and roofing

All structural work including fabrication and erection of structural steel shall be in accordance with IS: 800.

The maximum possible fabrication of structural steelworks shall be manufactured off-site in a fabrication shop.

All members shall be free from twists, kinks, buckles, or open joints. Steel before being fabricated shall be thoroughly wire brushed, cleaned of all scale and rust, and thoroughly straightened by approved methods that will not injure the materials being worked on.

Welding shall be continuous along the entire line of contact except where tack or intermittent welding is permitted. Where exposed, welds shall be cleaned of flux and slag and ground smooth.

Roofing sheet shall be Asbestos cement sheet corrugated of Trafford or Pre-painted galvanised steel sheet Trafford not less than 5mm thick.

Rain water collecting gutter shall be provided around the roof for collecting rain water for providing rain water harvesting system.

All steel members exposed to weather shall be cleaned and then 2 coats of anticorrosive Zink-Cromete Paint each 20 micron layer and then 2 coats of Industrial grade Enamel paint of approved make shall be applied.

Processing equipments

First Trommel or primary separation unit for separating high volume low density materials.

Type	: Rotary
Size	: To be designed according to the capacity of the plant (minimum 1200mm dia and 4000mm length)
Profile	: Incline (5 to 10^0)
Speed	: 6 to 10 rpm
Drive	: Hydraulic geared motor suitable capacity.
Mesh size	: 36 to 40 mm stainless steel
Painting	: Industrial grade

Second Trommel or Preliminary pre-finishing Trommel for separating compost from small pieces of bricks stones, wood pieces etc., which have passed through Ist separation system.

Type	: Rotary
Size	: To be designed according to the capacity of the plant (minimum 1200mm dia and 4000mm length)
Profile	: Incline (5 to 10^0)
Speed	: 6 to 10 rpm
Drive	: Hydraulic geared motor suitable capacity.
Mesh size	: 16 to 20 mm stainless steel
Painting	: Industrial grade

Third Trommel or Rotary Sieve for finished product.

Type	: Rotary
Size	: To be designed according to the capacity of the plant (minimum 1000mm dia and 2500mm length)
Profile	: Incline (5 to 10^0)
Speed	: 20 to 30 rpm
Drive	: Electric geared motor suitable capacity.
Mesh size	: 4to 6 mm stainless steel
Painting	: Industrial grade

In place of 3rd Trommel, Vibratory unit can be used with reciprocating movement, Electric motor, 4 to 6 mm screen wire mesh.

Conveyor belts

All feeding and rejection conveyor belts shall be designed for satisfying the capacity of the plant. Even though the minimum width shall be 780mm. and speed of the feeding conveyors shall be 2.5 to 5 Metres/Minutes and for rejection conveyor shall be 20 rpm. Conveyor belts shall be three ply nylon belt top 2mm rubber and bottom 1.5mm thick rubber coating.(3ply means three line sheet joined together).

Bucket Elevator with Drag feeding can be used for feeding to Vibro sieve. Speed shall be not more than 30 rpm.

Drive system

For drive system Hydraulic Power Pack with suitable capacity for running the trommels and conveyors.
The power pack should includes oil tank, water cooling system, pumps, pressure control, required capacity electric motor etc.

Electric control panel box

Electric control panel box should be designed suitable for the Hydraulic Power Pack with necessary Voltmeter, Ammeter, Timer block, MCB etc.

Finished product storage area and packing section

Finished product storage area should be designed with a capacity for storing minimum 60 days product safely**.** The storage area should be covered from the top with proper roof so as to prevent the material from possible rainfall. Sides of this area also should be covered with proper ventilation.

The same specifications of the compost plant shall be followed for the floor finishing and steel structural works

Bulk density of the garbage considered as 700Kg/cu.m. Assume the garbage reaching to the plant is 'x'MT. Then the volume will be x/0.7 cu.m.

Out of this, the volume of finished product will be approximate 25% of the incoming fresh garbage. That is the volume of the finished product /day will be 25% of x/0.7 cu.m.

Volume of 60 days product will be 60 X 0.25 X 'x'/0.7 = 15x/0.7 cu.m.

Consider the finished product can be heaped for an average height of 2.5m, then the area required for keeping the 60 days product will be 15x/0.7x2.5 = 15x/1.75 sq.m.

Internal Roads

Trafficable all weather road around the compost plant, finished product shed, to administrative building, laboratory, canteen, sanitary landfill area, leachate treatment plant, staff quarters and to all the service buildings shall be provided.

Road works to be carried out as per IRC standard specification.

1. Preparation of sub grade as per IRC item 305
2. Water bound macadam sub-base as per IRC item 401-3-1
3. Water bound macadam base course as per IRC item 404
4. Pre-mix chipping carpet with heavy seal coat as per IRC item 507

Water bound macadam sub-base

Metalling the road way 100 mm spread thickness compacted to 75mm using IRC grade -2 metal 60mm 70% and 36mm 30% (1m3 per 10m2) and binding materials @ 0.2m3 per10m2 we rolling, spreading broken stone to template, rolling dry to compaction from side to centre until the movement of broken stone cease, watering profusely and rolling until the finish cream up and fill the voids of the stones, then spreading the gravelly earth and sweeping into the joints, watering and re rolling until the gravelly earth has worked into all the crevases and only a thin coat of slurry remains, then take of the roller and allow to set hard for 24 hrs and rolling next day until any deformality is rectified, including fencing, lighting, watching and maintaining the surface free of routes for 15 days after completion.

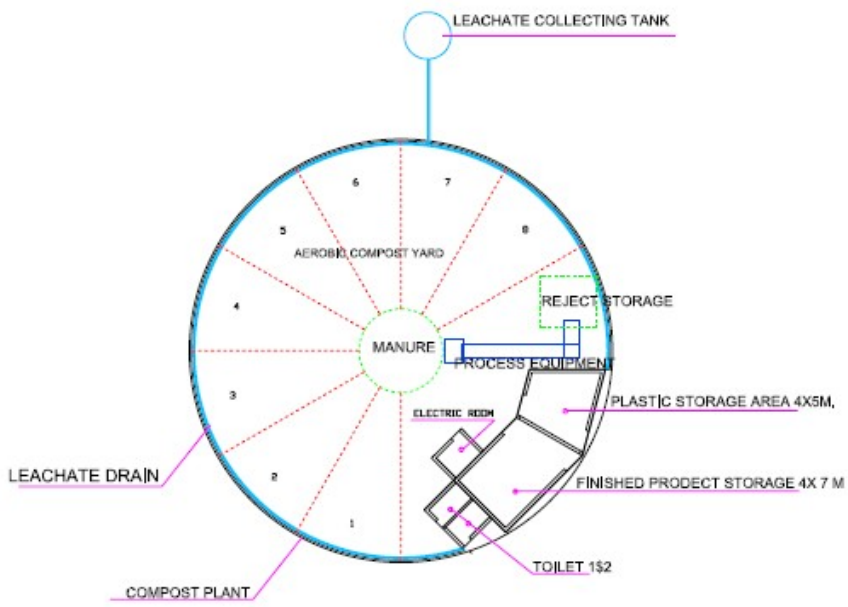
Water bound macadam base course

Metalling the road way 100 mm spread thickness compacted to 75mm using 36mm metal (1m3 per 10m2) and binding materials @ 0.15m3 per10m2 we rolling, spreading broken stone to template, rolling dry to compaction from side to centre until the movement of broken stone cease, watering profusely and rolling until the finish cream up and fill the voids of the stones, then spreading the gravelly earth and sweeping into the joints, watering and re rolling until the gravelly earth has worked into all the crevasses and only a thin coat of slurry remains, then take of the roller and allow to set hard for 24 hrs and rolling next day until any deformality is rectified, including fencing, lighting, watching and maintaining the surface free of routes for 15 days after completion.

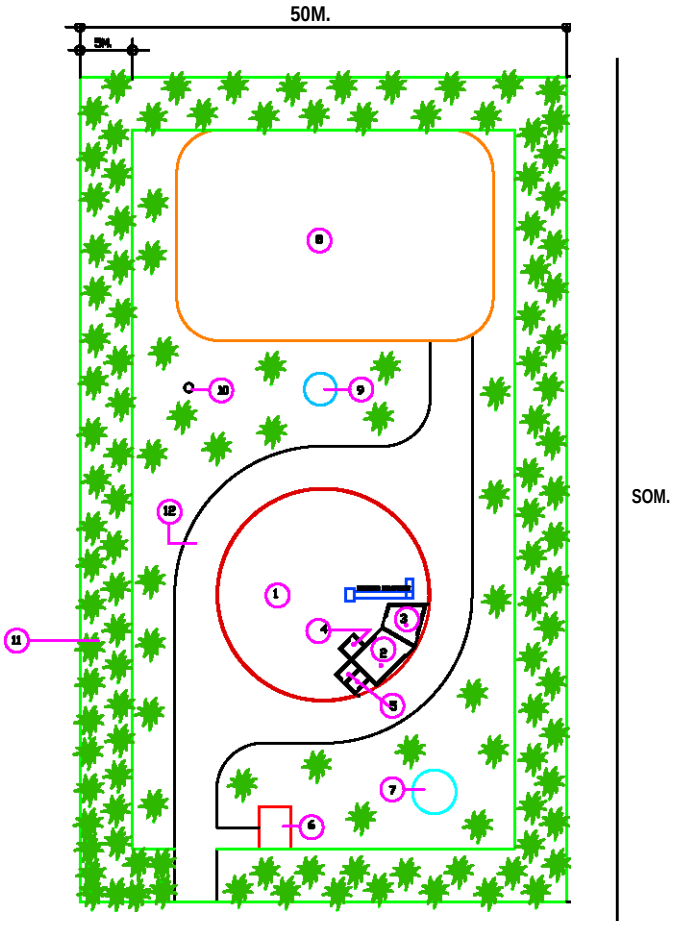
20mm pre-mixed chipping carpet

Providing 20mm pre-mixed chipping carpet over WMM surface with contractor's broken stone after thoroughly cleaning the base with wire brushes, bass brooms and applying a priming coat of 7.5 Kg of bitumen per 10 m2 and spreading the hot pre-mix(formed of 0.25m3 of contractor's 12mm broken stone and 12.96Kg of bitumen per 10m2) rolling to dense surface, then spreading the seal coat(comprising of a hot pre-mix of 0.09m3 of 6mm contractor's broken stone and 8.64Kg of bitumen per 10m2)again rolling including the cost of bitumen, oils and fuel, hire of bass brooms, camber board, roller and other machines, watching, lighting and other charges etc. complete including cost and conveyance of broken stone.

Annexure - 2



WINDROW COMPOST PLANT 5 MT – PLAN



CD COMPOST PLANT 24M. DIA

G BIO GAS PLANT

® FINISHED PRODECT STORAGE 4X7M

0 LANDFILL 30x20M.

O PLASTIC STORAGE AREA 3X5M.

O LTP

0 ELECTRIC ROOM

@ MONITORING WELL

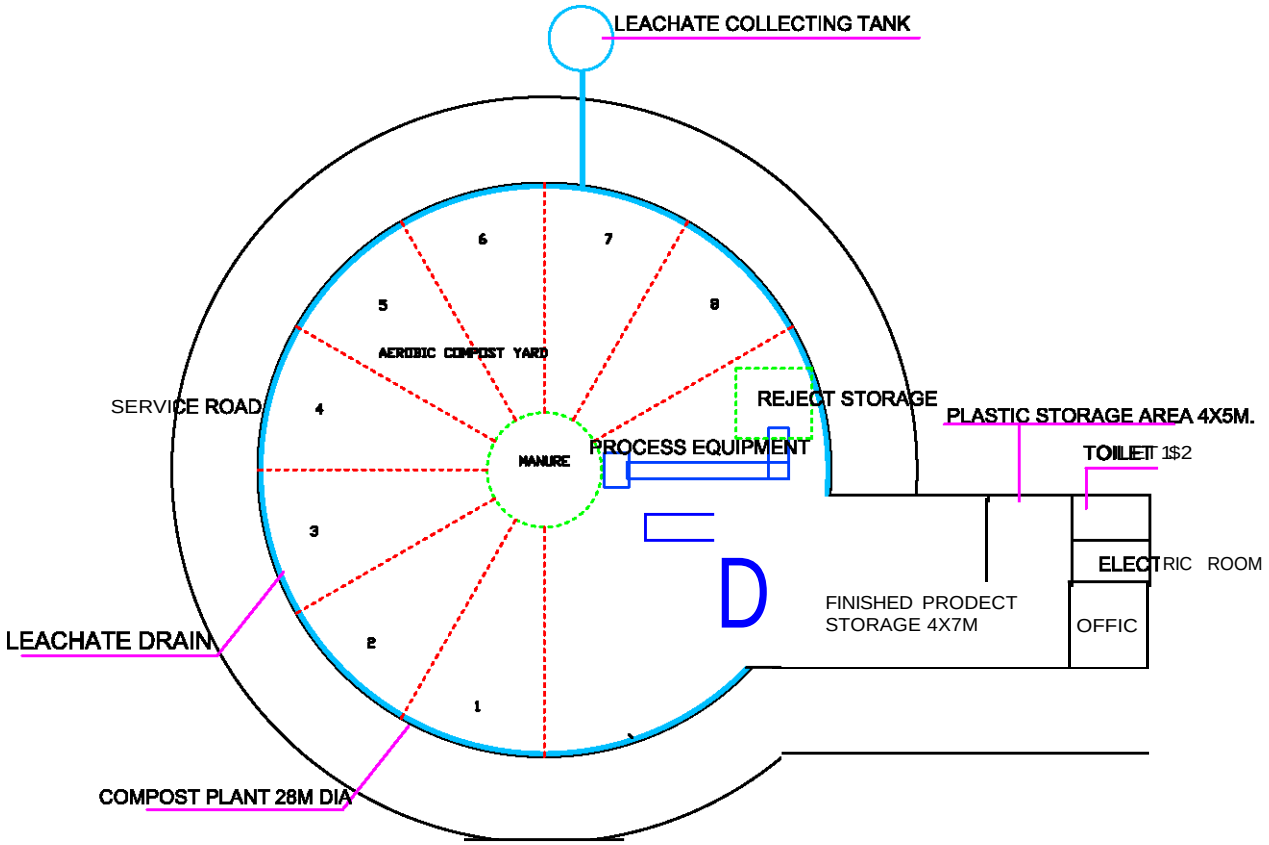
TOILET 1$2

@ GREENBELT

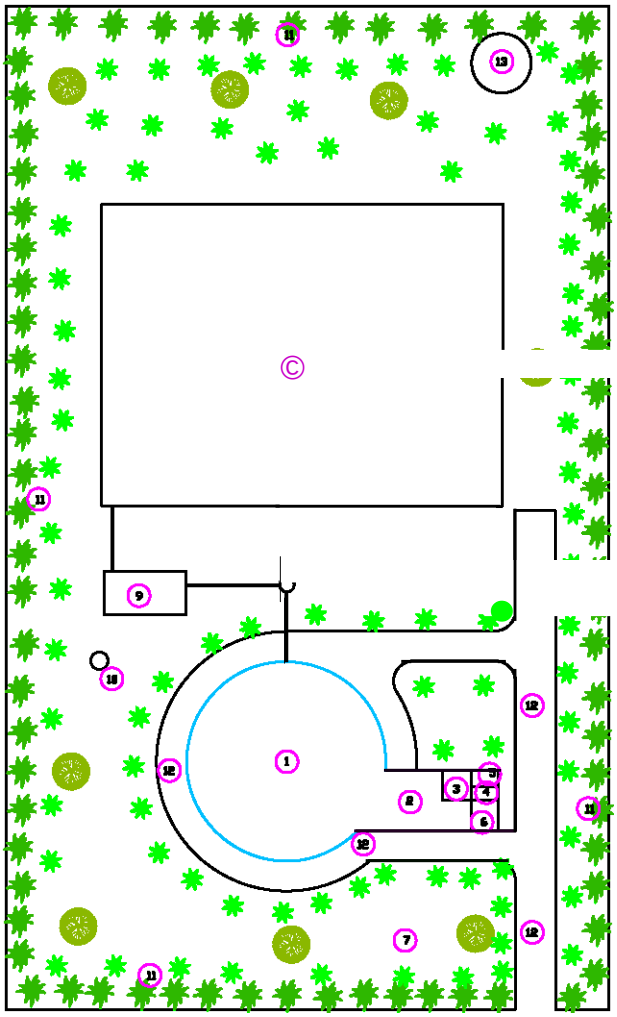
G ADMINISTRATIVE BUILDING

@ TAR ROAD

GENERAL LAY OUT OF WINDROW COMPOST PLANT 5MT



WINDROW COMPOST PLANT 10 MT -PLAN



0 CCMPCST PLANT 30M. DIA

FIN SHED PRCDECT STCRAGE 6X7M

0 PLASTIC STORAGE AREA '4X5M.

8 ELECTRIC ROOM

TOILET 1$2

G ADMIN STRATIVE BU LDING

G BIC GAS PLANT

0 LANDFILL 50x30M.

0 LTP

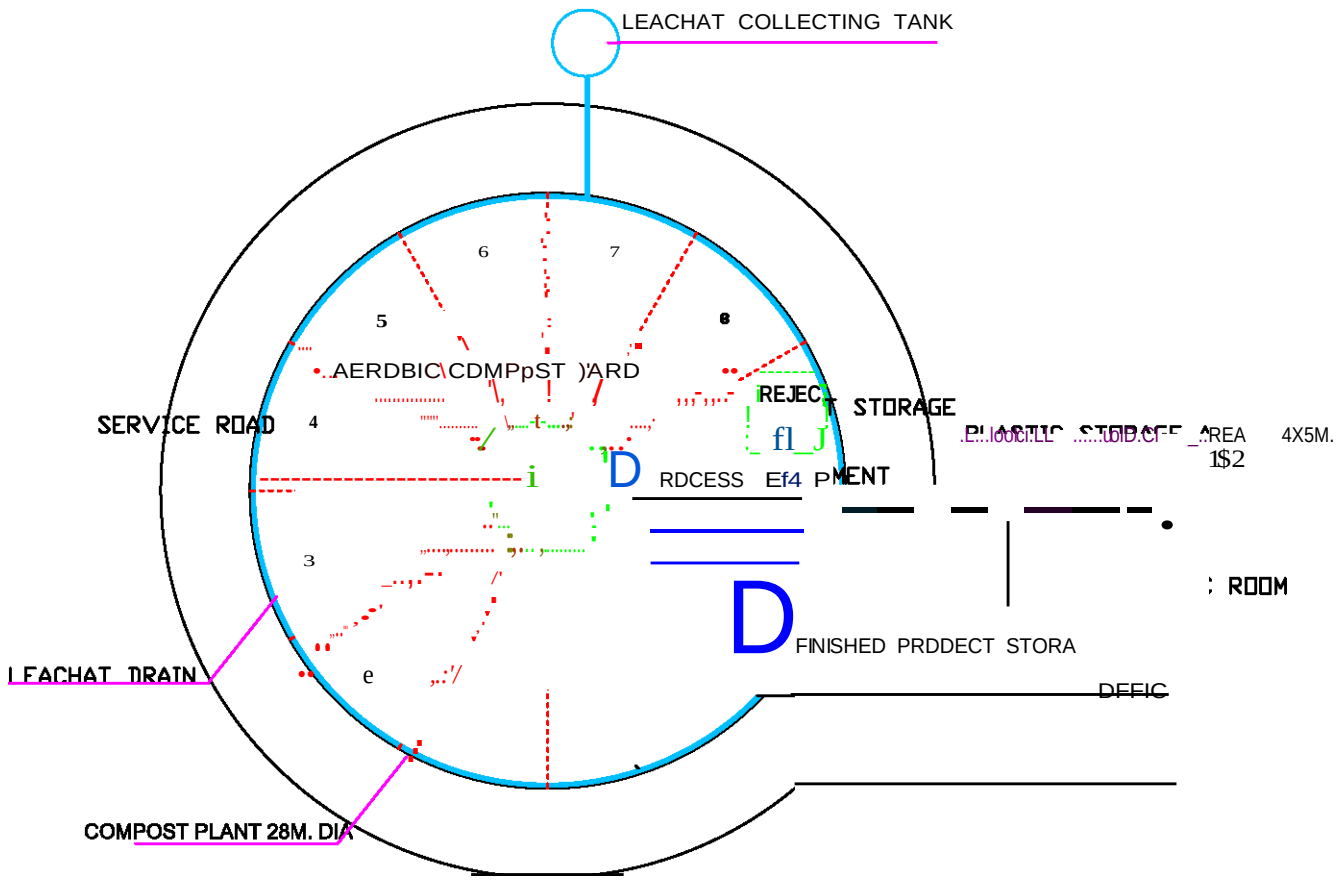
@ MCNITCRING 'w'ELL

G GREEN BELT

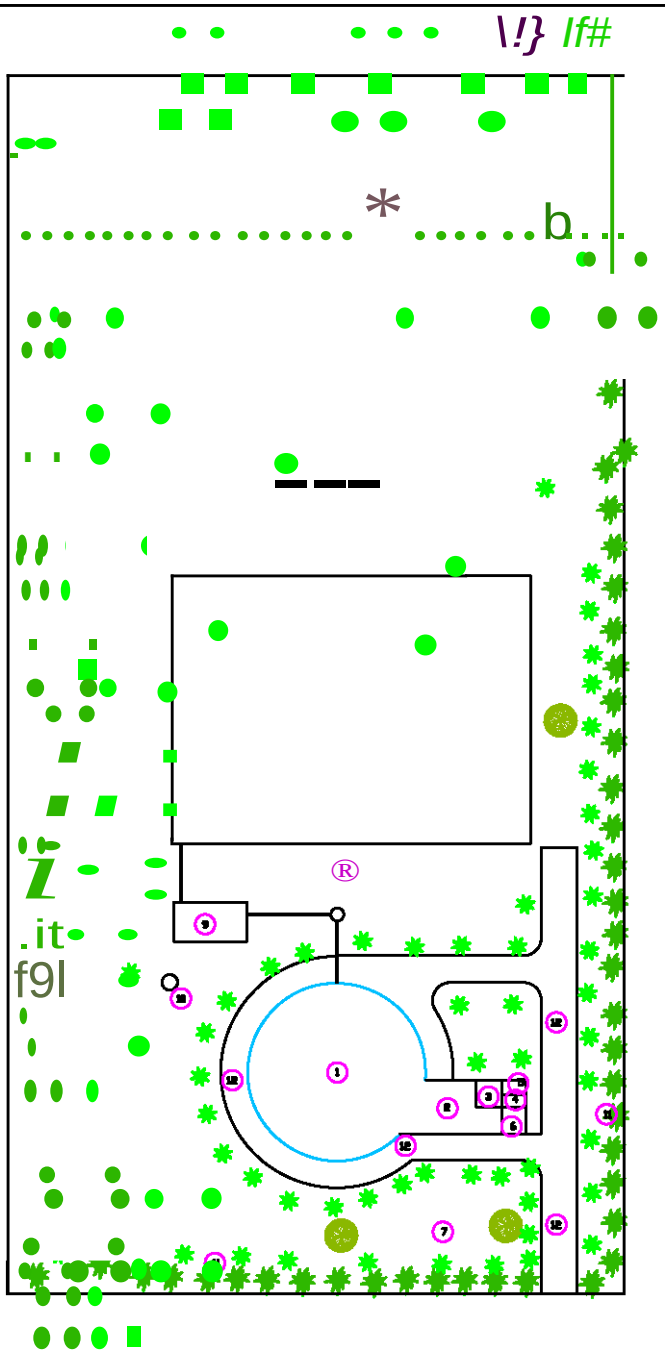
@ TAR RCAD

@ CH TANK

GENERAL LAY OUT OF WINDROW COMPOST PLANT 10MT



WINDROW COMPOST PLANT 50 MT -PLAN



0 COMPOST PLANT 45M. DIA

0 LANDFILL 100X60M.

© FINISHED PlitCDECT smlitAGE 10X8M

0 LTP

PLASTIC smlitAGE AlitEA 6X6M.

@ MCNimlitING YELL

0 ELECTlitIC litCCM

® GlitEEN BELT

TmLET 152

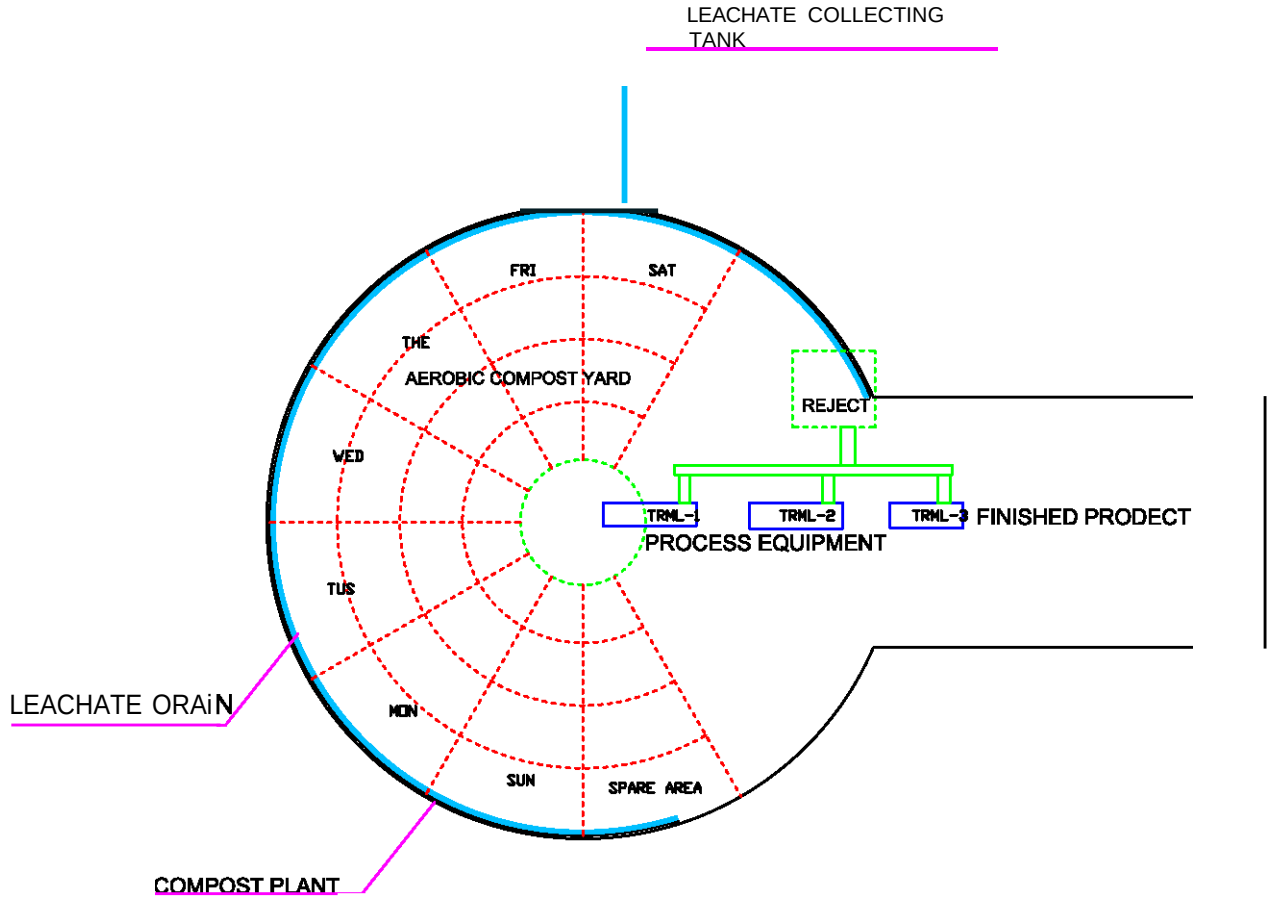
@ TM litCAD

G ADMIN STlitATIVE BUILDING

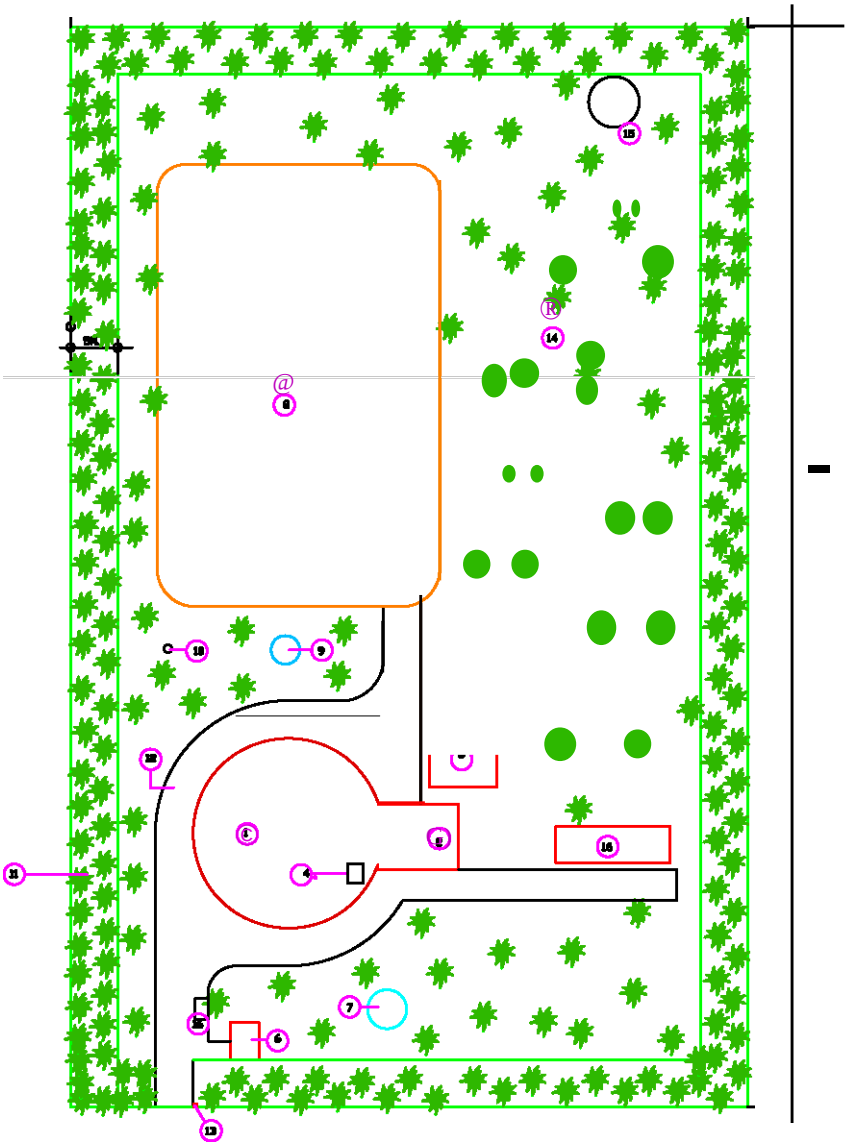
@ [].I TAN<

G BID GAS PLANT

GENERAL LAY OUT OF WINDROW COMPOST PLANT 50MT



WINDROW COMPOST PLANT 100 MT - PLAN



0 COMPOST PLANT 80M. DIA

Ⓒ FINISHED PRODECT STORAGE 20x15M

Ⓒ PLASTIC STORAGE AREA 10x6M.

Ⓒ ELECTRIC ROOM

TOILET BLOCK

G ADMINISTRATIVE BUILDING ANDLAB50M2

G BIO GAS PLANT

Ⓒ LANDFILL 100x150M.

0m>

@ MONITORING WELL

@ GREEN BELT

O TAR ROAD

@ WATCH MAN SHED

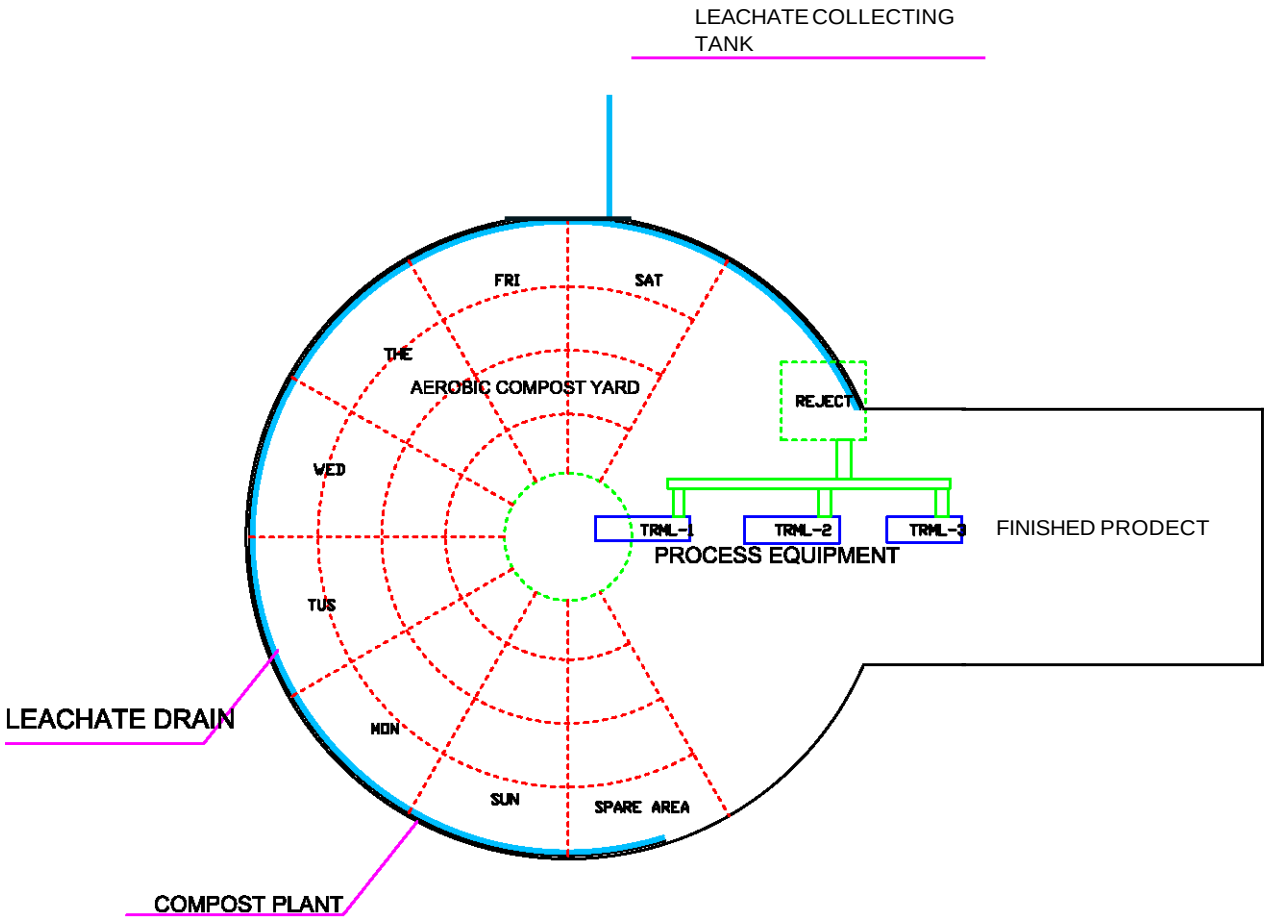
Ⓡ FUTER LAND Fill.

@ OH WATER TANK

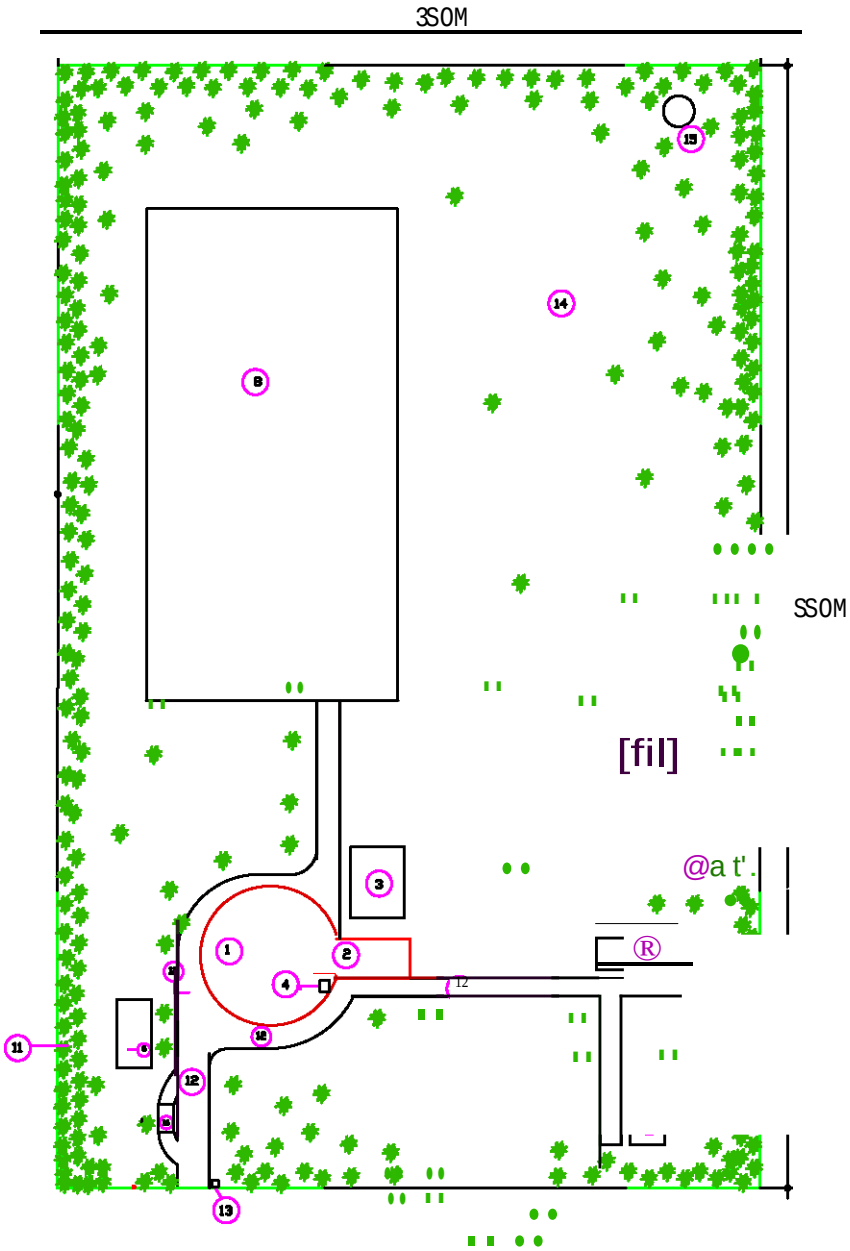
@ WEIGH BRIDGE

@ SERVICE STATION 20X7M.

GENERAL LAY OUT OF WINDROW COMPOST PLANT 100MT



WINDROW COMPOST PLANT 250 MT -PLAN



0 CIIfDST PLANT 121111. DIA

© rINISIEI PRIIIECT STIRAGE 311•211M

0 SHREDDER 15XIOM.

© ELECTRIC RIIIII

TDILET aJICIC r.11311.

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G 1111:1 IiAS PL.NIT

O LNIIFILL II!D•2SIM.

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@ IDIITIIIIING YELL

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® TM MW!

@ VATCH -SI£D

@ FIJ1DI LNIII F1LI.

@ III YATER TANIC

16GMI!@ VEiliH IRIDIiE

@ SERVICE STATiIII II!OX7M.

@ RDr PLANT 30XISM.

@ CANTEENJOX6M.

GENERAL LAY OUT OF WINDROW COMPOST PLANT 250MT

ANNEXURE – 3

Model Estimate for SWM plant using Windrow Composting Technology

SWM plants 5 MT

Sl. No.	Item	Amount
1	Plant building and other service building such as administrative building, canteen, electrical room, toilet block, laboratory etc	4950000.00
2	Sanitary landfill and LTP	1800000.00
3	Internal road, boundary wall and green area development	575000.00
4	Processing machinery	1500000.00
5	Material handling equipments	100000.00
6	Shredder for plastic	
7	Water supply system including over head water tank.	200000.00
8	Electrification	150000.00
		9275000.00

SWM plant 10 MT

Sl. No.	Item	Amount (Rs)
1	Plant building and other service building such as administrative building, canteen, electrical room, toilet block, laboratory etc	8050000.00
2	Sanitary landfill and LTP	3250000.00
3	Internal road, boundary wall and green area development	675000.00
4	Processing machinery	1800000.00
5	Material handling equipments	100000.00
6	Shredder for plastic	
7	Water supply system including over head water tank.	200000.00
8	Electrification	150000.00
		14225000.00

SWM plant 50 MT

Sl. No.	Item	Amount
1	Plant building and other service building such as administrative building, canteen, electrical room, toilet block, laboratory etc	18300000.00
2	Sanitary landfill and LTP	12350000.00
3	Internal road, boundary wall and green area development	1700000.00
4	Processing machinery	7500000.00
5	Material handling equipments including way bridge	5600000.00
6	Shredder for plastic	1050000.00
7	Water supply system including over head water tank.	600000.00
8	Electrification	1100000.00
		48200000.00

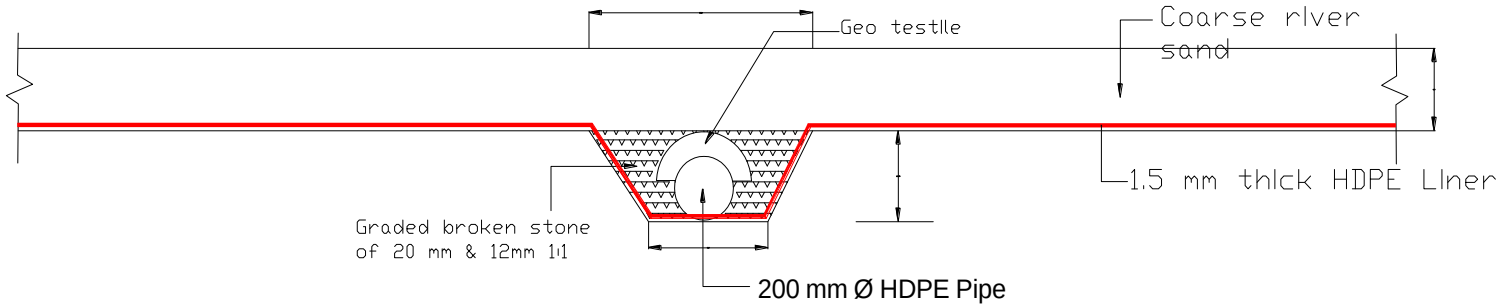
SWM plant 100 MT

Sl. No.	Item	Amount
1	Plant building and other service building such as administrative building, canteen, electrical room, toilet block, laboratory etc	54700000.00
2	Sanitary landfill and LTP	39000000.00
3	Internal road, boundary wall and green area development	2550000.00
4	Processing machinery	15000000.00
5	Material handling equipments including way bridge	11100000.00
6	Shredder for plastic	2000000.00
7	Water supply system including over head water tank.	1800000.00
8	Electrification	1550000.00
		127700000.00

SWM plant 250 MT

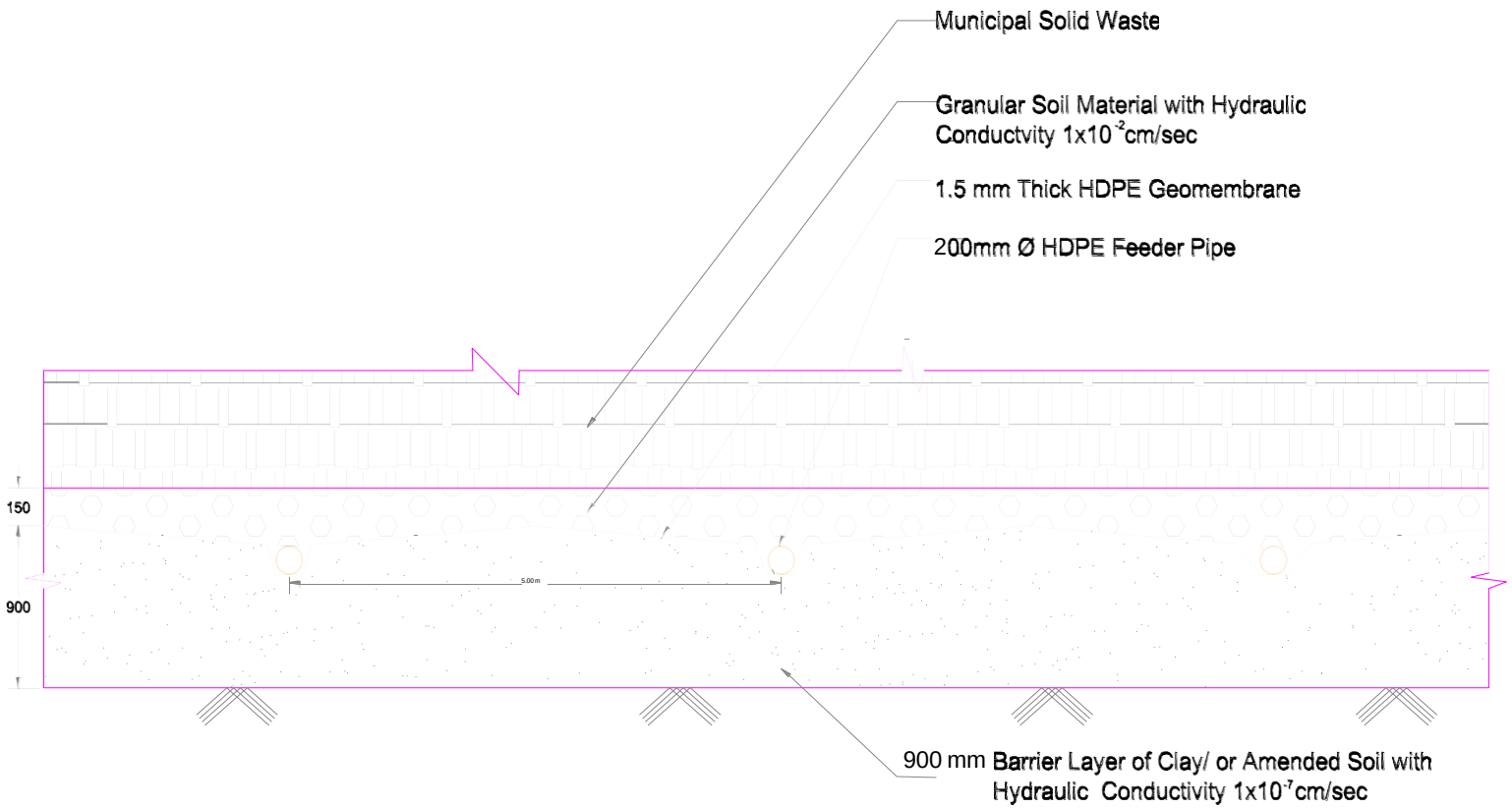
Sl. No.	Item	Amount
1	Plant building and other service building such as administrative building, canteen, electrical room, toilet block, laboratory etc	116300000.00
2	Sanitary landfill and LTP	59000000.00
3	Internal road, boundary wall and green area development	6950000.00
4	Processing machinery	18000000.00
5	Material handling equipments including way bridge	16500000.00
6	Shredder for plastic	2550000.00
7	Water supply system including over head water tank.	3000000.00
8	Electrification	2500000.00
		224800000.00

ANNEXURE - 4

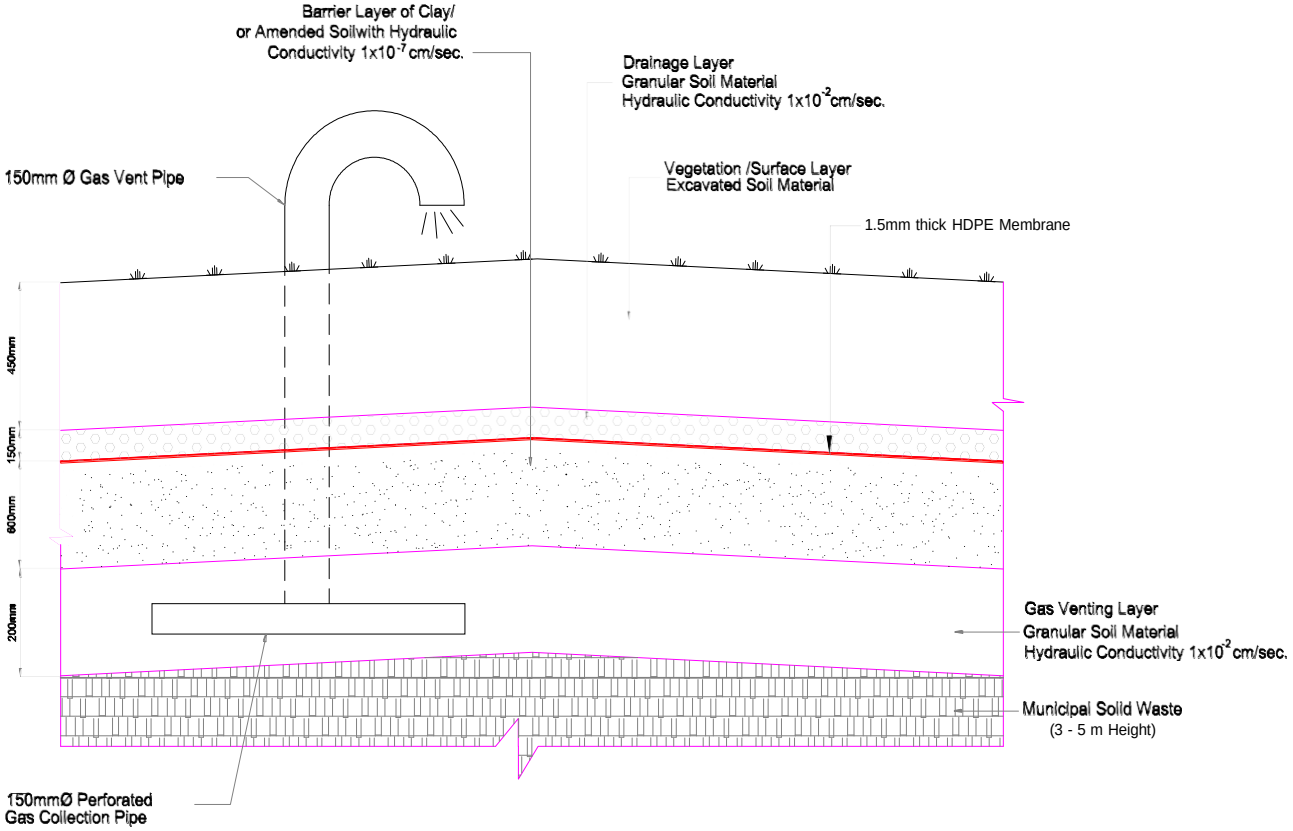


CROSS SECTION OF PIPE

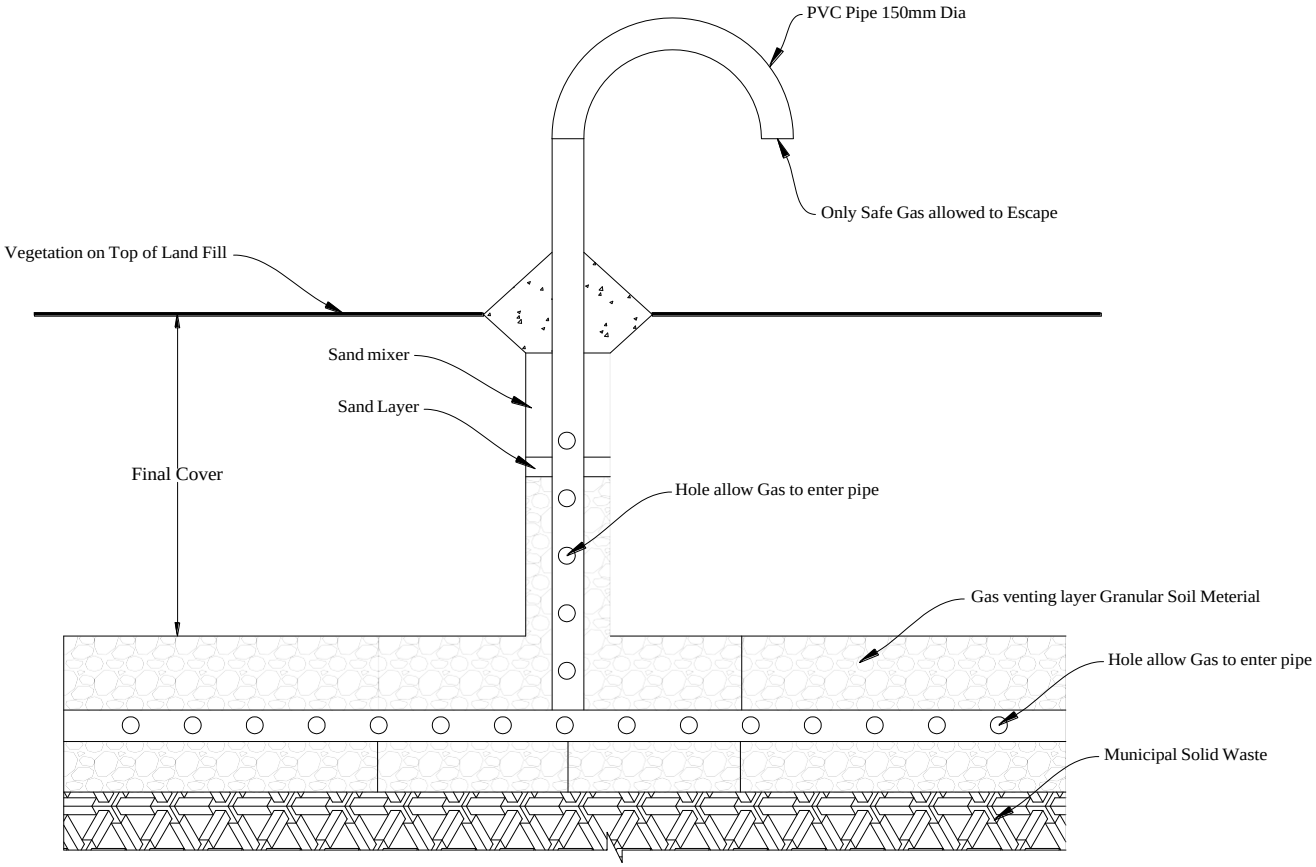
LAND FILL - CROSS SECTION OF PIPE



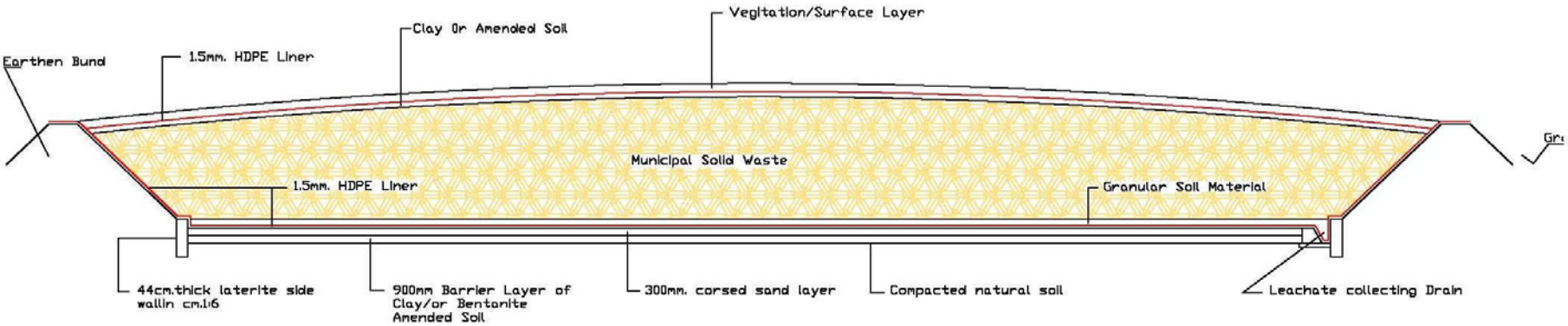
LAND FILL - CROSS SECTION OF BOTTOM LINER



LAND FILL - CROSS SECTION OF FINAL COVER



LAND FILL - CROSS SECTION OF VENT PIPE



LAND FILL - CROSS SECTION OF SANITARY LAND FILL