

STUDY OF WASTE TO ENERGY CONVERSION, PROVEN TECHNOLOGY USING INCINERATION OF MUNICIPAL SOLID WASTE

A thesis submitted towards partial fulfilment of the requirements for the degree of

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CERTIFICATE OF RECOMMENDATION

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All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by this rules and conduct, I have fully cited and referred all material and results that are not original to this work.

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**This Thesis Work is
dedicated to my parents**

ABSTRACT

Energy plays significant role in the development of a nation. The conventional sources, though exhausting and not environment friendly are being increasingly used. Looking at limited supplies and various environment problems associated with its uses, renewable energy sources are getting attention. Municipal solid waste [MSW] is getting importance in recent years. . The MSW management involves collection, transportation, handling and conversion to energy by biological and thermal routes. The present paper reports the results of physical & chemical analysis, used to select the most appropriate method of energy conversion. Based on the energy potential available, the feasibility of energy conversion through using available waste has been carried out. The present work can be categorized into two parts.

In the first part of this study , the possibility was explored to collect municipal solid waste from Pramod Nagar Dumping yard and harvesting of energy from it by incineration . The physical and chemical parameters of 10 samples were tested in laboratory and then the net average calorific value was determined . Multiplying this data with secondary data collected from municipality about daily solid waste generation , the probable energy harvesting possibility is determined .

In the second part , a practical field project was carried out at Titagarh Thermal Power Plant , North 24 Parganas, West Bengal . All relevant parameters related to electricity generation was studied and collected . From the heat energy produced by incinerating the municipal solid waste of South Dum Dum Municipality , how much percentage electricity of the said power plant can be generated was evaluated . Accordingly how much fossil fuel consumption can be reduced per day basis was shown. Designing an incineration plant with this capacity level of energy generation was calculated and established .

In this study chapter 1 delineates a brief description of solid waste management , Historical background of solid waste , collection and transfer of solid waste , classification of solid waste, overview of different technological options of energy harvesting and their suitability, description of biogas, its formation mechanism as well as description and comparison of different type biogas plants implemented in India and energy harvesting with incineration technology . Chapter 2 depicts the objective and scope of this study. Chapter 3 reveals some studies of the researchers, carried out with different input materials with different models are discussed in national and international level. Chapter 4 narrates the overall methodology used in this study. Chapter 5 reports the observations and corresponding validation obtained from this study. Chapter 6 deals with field review of a power plant and review of electricity generation with the aid of solid waste harvested energy by incineration technology . Chapter 7 of this study illustrate the design principle of incineration plant . Chapter 8 conclude with some recommendations and future scope of this present work.

Key Words : Renewable Energy Sources , Municipal Solid Waste (MSW) , Incineration

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1. INTRODUCTION

1.0 INTRODUCTION

Energy crisis and waste disposal are the two main interdependent problems of main concern in a developed country like India in the present scenario. India is mainly dependent in thermal power means of energy production and is the third largest consumer of coal in the world. . MSW generation per capita in India ranges from approximately 0.17 kg per person per day in small towns to approximately 0.62 kg per person per day in cities out of which 40-50 percent is the organic and biodegradable which is expected to reach 0.7 kg by the year 2030. [1]

It is well recognized that municipal solid waste (MSW) is a source of renewable energy due to its composition, e.g. wood or food as biomass materials . As one of most popular approaches, waste-to-energy incineration helps to reduce the amount of waste sent to the landfill . Waste-to-energy incineration can not only deal with the rapid growing amount of MSW arguably due to the expansion of the population but also satisfy the demand for energy by means of heat and electricity . This indeed forms part of renewable energy production strategies .

Absolute waste production is anticipated, to rise continuously both on a global scale and unanimously on every continent (Kaza et al., 2018). High correlations between economic growth and waste production suggest that sharp increases in waste generation will eventually occur in regions that are as yet characterized by low income levels and weak economic performances. Simultaneously, expected population growth within the respective regions entails further intensification in the realm of waste production. Corresponding tendencies are least expected in developed countries, but they are already characterized by high waste production rates per capita.

The volume of municipal solid waste (MSW) generated globally from urban areas is increasing rapidly as a result of expanding human population and rapid urbanization . The World Bank estimates that solid waste generated from urban areas globally will increase from roughly 3.5 million tonnes per day currently generated to 6.1 million tonnes per day by 2025 . MSW incineration (MSWI) plays a pivotal role in not only managing this expanding volume of waste but also in recovering energy that can be used to supplement traditional supplies . With more than 80% of the global primary energy share being met from fossil fuels . MSWI can play a crucial role in offsetting fossil fuel consumption and increasing the renewable energy share while at the same time assisting with waste treatment .[2]

The rising piles of garbage in urban areas caused by rapid urbanization and industrialization throughout India represent another source of nonconventional energy. An estimated 50 million tonnes of solid waste and approximately 6,000 million cubic meters of liquid waste are generated annually in the urban areas of India. Good potential exists for generating approximately 2,600 MW of power from urban and municipal wastes and approximately 1,300 MW from industrial wastes in India. A total of 48 projects with aggregate capacity of about 69.62 MW have been installed in the country thereby utilising only 1.8% of the potential that exists.[3] As Municipal solid waste (MSW) is regarded as an important source of renewable energy, these results not only provide a better understanding of global hotspots in the specific research related to the waste-to-energy incineration, but may also provide useful information for the broader research area of renewable energy.

Incineration converts the waste material into heat, flue gas and ash which are released into the atmosphere without any further treatment for usage. In this context, the paper studies the types of waste products produced which can be further used in an effective way by proper treatment reaction and analysis. Heat which is in major percentage can be used to generate electric power. Flue gases contain traces of nitrogen, carbon dioxide and sulfur dioxide, each of which has better utilization when used optimally. Nitrogen produced can be used as fertilizers to increase the productivity of crops, carbon dioxide can be used as fire extinguishers and sulfur once extracted from sulphur dioxide can be used in dental treatment to discompose waste amalgam without getting it exposed to outside air. Ash is obtained in the form of solid lumps which can be used for construction purposes.

Understanding the scenario, theoretical as well as field review has been conducted on the waste to energy conversion through incineration procedure. As a part of the survey the calorific value of different MSW samples were analysed . The average calorific value of the samples from the dumping ward was evaluated which highlighted the amount of heat and electrical energy generation possibility from the Municipal solid waste .

1.0.1 : SOLID WASTE

Solid wastes are the organic and inorganic waste materials such as product packaging, grass clippings, furniture, clothing, bottles, kitchen refuse, paper, appliances, paint cans, batteries, etc., produced in a society, which do not generally carry any value to the first user(s). Solid waste means any garbage or refuse, sludge from a wastewater treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, resulting from industrial, commercial, mining, and agricultural operations, and from community activities.[4]

1.0.2 : SOLID WASTE MANAGEMENT

Solid-waste management covers the collecting, treating, and disposing of solid material that is discarded because it has served its purpose or is no longer useful. Improper disposal of municipal solid waste can create unsanitary conditions, and these conditions in turn can lead to pollution of the environment and to outbreaks of vector-borne disease that is, diseases spread by rodents and insects. The tasks of solid-waste management present complex technical challenges. They also pose a wide variety of administrative, economic, and social problems that must be managed and solved.

1.0.3 : HISTORICAL BACKGROUND

In ancient cities, wastes were thrown onto unpaved streets and roadways, where they were left to accumulate. It was not until 320 BCE in Athens that the first known law forbidding this practice was established. At that time a system for waste removal began to evolve in Greece and in the Greek-dominated cities of the eastern Mediterranean. In ancient Rome, property owners were responsible for cleaning the streets fronting their property. But organized waste collection was associated only with state-sponsored events such as parades. Disposal methods were very crude, involving open pits located just outside the city walls. As populations increased, efforts were made to transport waste farther out from the cities.

After the fall of Rome, waste collection and municipal sanitation began a decline that lasted throughout the Middle Ages. Near the end of the 14th century, scavengers were given the task of carting waste to dumps outside city walls. But this was not the case in smaller towns, where most people still threw waste into the streets. It was not until 1714 that every city in England was required to have an official scavenger. Toward the end of the 18th century in America, municipal collection of garbage was begun in Boston, New York City, and Philadelphia. Waste disposal methods were still very crude, however. Garbage collected in Philadelphia, for example, was simply dumped into the Delaware River downstream from the city.

1.0.4 DEVELOPMENT IN WASTE MANAGEMENT

A technological approach to solid-waste management began to develop in the latter part of the 19th century. Watertight garbage cans were first introduced in the United States, and sturdier vehicles were used to collect and transport wastes. A significant development in solid-waste treatment and disposal practices was marked by the construction of the first refuse incinerator in England in 1874. By the beginning of the 20th century, 15 percent of major American cities were incinerating solid waste. Even

then, however, most of the largest cities were still using primitive disposal methods such as open dumping on land or in water.

Technological advances continued during the first half of the 20th century, including the development of garbage grinders, compaction trucks, and pneumatic collection systems.[5] By mid-century, however, it had become evident that open dumping and improper incineration of solid waste were causing problems of pollution and jeopardizing public health. As a result, sanitary landfills were developed to replace the practice of open dumping and to reduce the reliance on waste incineration. In many countries waste was divided into two categories, hazardous and non hazardous, and separate regulations were developed for their disposal. Landfills were designed and operated in a manner that minimized risks to public health and the environment. New refuse incinerators were designed to recover heat energy from the waste and were provided with extensive air pollution control devices to satisfy stringent standards of air quality. Modern solid-waste management plants in most developed countries now emphasize the practice of recycling and waste reduction at the source rather than incineration and land disposal.[6]

1.0.5 GENERATION & STORAGE

Rates of solid-waste generation vary widely. In the United States municipal refuse is generated at an average rate of approximately 2 kg (4.5 pounds) per person per day. Japan generates roughly half this amount, yet in Canada the rate is 2.7 kg (almost 6 pounds) per person per day. In some developing countries the average rate can be lower than 0.5 kg (1 pound) per person per day. These data include refuse from commercial, institutional, and industrial as well as residential sources. The actual rates of refuse generation must be carefully determined when a community plans a solid-waste management project.

Most communities require household refuse to be stored in durable, easily cleaned containers with tight-fitting covers in order to minimize rodent or insect infestation and offensive odours. Galvanized metal or plastic containers of about 115-litre (30-gallon) capacity are commonly used, although some communities employ larger containers that can be mechanically lifted and emptied into collection trucks. Plastic bags are frequently used as liners or as disposable containers for curbside collection.

Where large quantities of refuse are generated—such as at shopping centres, hotels, or apartment buildings—dumpsters may be used for temporary storage until the waste is collected. Some office and commercial buildings use on-site compactors to reduce the waste volume.

1.0.6 : COLLECTING & TRANSPORTING

Proper solid-waste collection is important for the protection of public health, safety, and environmental quality. It is a labour-intensive activity, accounting for approximately three-quarters of the total cost of solid-waste management. Public employees are often assigned to the task, but sometimes it is more economical for private companies to do the work under contract to the municipality or for private collectors to be paid by individual home owners. A driver and one or two loaders serve each collection vehicle. These are typically trucks of the enclosed, compacting type, with capacities up to 30 cubic metres (40 cubic yards). Loading can be done from the front, rear, or side. Compaction reduces the volume of refuse in the truck to less than half of its loose volume.

The task of selecting an optimal collection route is a complex problem, especially for large and densely populated cities. An optimal route is one that results in the most

efficient use of labour and equipment, and selecting such a route requires the application of computer analyses that account for all the many design variables in a large and complex network. Variables include frequency of collection, haulage distance, type of service, and climate. Collection of refuse in rural areas can present a special problem, since the population densities are low, leading to high unit costs.

Refuse collection usually occurs at least once per week because of the rapid decomposition of food waste. The amount of garbage in the refuse of an individual home can be reduced by garbage grinders, or garbage disposals. Ground garbage puts an extra load on sewerage systems, but this can usually be accommodated. Many communities now conduct source separation and recycling programs, in which homeowners and businesses separate recyclable materials from garbage and place them in separate containers for collection. In addition, some communities have drop-off centres where residents can bring recyclables.[7]

1.0.7 :TRANSFER STATION

If the final destination of the refuse is not near the community in which it is generated, one or more transfer stations may be necessary. A transfer station is a central facility where refuse from many collection vehicles is combined into a larger vehicle, such as a tractor-trailer unit. Open-top trailers are designed to carry about 76 cubic metres (100 cubic yards) of uncompacted waste to a regional processing or disposal location. Closed compactor-type trailers are also available, but they must be equipped with ejector mechanisms. In a direct discharge type of station, several collection trucks empty directly into the transport vehicle. In a storage discharge type of station, refuse is first emptied into a storage pit or onto a platform, and then machinery is used to hoist or push the solid waste into the transport vehicle. Large transfer stations can handle more than 500 tons of refuse per day.

1.0.8 : SOLID WASTE TRATEMENT & DISPOSAL

Once collected, municipal solid waste may be treated in order to reduce the total volume and weight of material that requires final disposal. Treatment changes the form of the waste and makes it easier to handle. It can also serve to recover certain materials, as well as heat energy, for recycling or reuse.

1.0.9 INCINERATION

Burning is a very effective method of reducing the volume and weight of solid waste, though it is a source of greenhouse gas emissions. In modern incinerators the waste is burned inside a properly designed furnace under very carefully controlled conditions. The combustible portion of the waste combines with oxygen, releasing mostly carbon dioxide, water vapour, and heat. Incineration can reduce the volume of uncompacted waste by more than 90 percent, leaving an inert residue of ash, glass, metal, and other solid materials called bottom ash. The gaseous by-products of incomplete combustion, along with finely divided particulate material called fly ash, are carried along in the incinerator airstream. Fly ash includes cinders, dust, and soot. In order to remove fly ash and gaseous by-products before they are exhausted into the atmosphere, modern incinerators must be equipped with extensive emission control devices. Such devices include fabric baghouse filters, acid gas scrubbers, and electrostatic precipitators. Bottom ash and fly ash are usually combined and disposed of in a landfill. If the ash is found to contain toxic metals, it must be managed as a hazardous waste.

Municipal solid-waste incinerators are designed to receive and burn a continuous supply of refuse. A deep refuse storage pit, or tipping area, provides enough space for about one day of waste storage. The refuse is lifted from the pit by a crane equipped with a bucket or grapple device. It is then deposited into a hopper and chute above the furnace and released onto a charging grate or stoker. The grate shakes and moves waste through the furnace, allowing air to circulate around the burning material. Modern incinerators are usually built with a rectangular furnace, although rotary kiln furnaces and vertical circular furnaces are available. Furnaces are constructed of refractory bricks that can withstand the high combustion temperatures.

Combustion in a furnace occurs in two stages: primary and secondary. In primary combustion, moisture is driven off, and the waste is ignited and volatilized. In secondary combustion, the remaining unburned gases and particulates are oxidized, eliminating odours and reducing the amount of fly ash in the exhaust. When the refuse is very moist, auxiliary gas or fuel oil is sometimes burned to start the primary combustion.

In order to provide enough oxygen for both primary and secondary combustion, air must be thoroughly mixed with the burning refuse. Air is supplied from openings beneath the grates or is admitted to the area above. The relative amounts of this under fire air and overfire air must be determined by the plant operator to achieve good combustion efficiency. A continuous flow of air can be maintained by a natural draft in a tall chimney or by mechanical forced-draft fans.[8]

1.0.10 : ENERGY RECOVERY

The energy value of refuse can be as much as one-third that of coal, depending on the paper content, and the heat given off during incineration can be recovered by the use of a refractory-lined furnace coupled to a boiler. Boilers convert the heat of combustion into steam or hot water, thus allowing the energy content of the refuse to be recycled. Incinerators that recycle heat energy in this way are called waste-to-energy plants. Instead of a separate furnace and boiler, a water-tube wall furnace may also be used for energy recovery. Such a furnace is lined with vertical steel tubes spaced closely enough to form continuous sections of wall. The walls are insulated on the outside in order to reduce heat loss. Water circulating through the tubes absorbs heat to produce steam, and it also helps to control combustion temperatures without the need for excessive air, thus lowering air pollution control costs.

Waste-to-energy plants operate as either mass burn or refuse-derived fuel systems. A mass burn system uses all the refuse, without prior treatment or preparation. A refuse-derived fuel system separates combustible wastes from noncombustibles such as glass and metal before burning. If a turbine is installed at the plant, both steam and electricity can be produced in a process called cogeneration.[9]

Waste-to-energy systems are more expensive to build and operate than plain incinerators because of the need for special equipment and controls, highly skilled technical personnel, and auxiliary fuel systems. On the other hand, the sale of generated steam or electricity offsets much of the extra cost, and recovery of heat energy from refuse is a viable solid-waste management option from both an engineering and an economic point of view. About 80 percent of municipal refuse incinerators in the United States are waste-to-energy facilities.[10]

1.0.11 COMPOSTING

Another method of treating municipal solid waste is composting, a biological process in which the organic portion of refuse is allowed to decompose under carefully controlled conditions. Microbes metabolize the organic waste material and reduce its volume by as

much as 50 percent. The stabilized product is called compost or humus. It resembles potting soil in texture and odour and may be used as a soil conditioner or mulch.

Composting offers a method of processing and recycling both garbage and sewage sludge in one operation. As more stringent environmental rules and siting constraints limit the use of solid-waste incineration and landfill options, the application of composting is likely to increase. The steps involved in the process include sorting and separating, size reduction, and digestion of the refuse.

1.0.12 SORTING & SHREDDING

The decomposable materials in refuse are isolated from glass, metal, and other inorganic items through sorting and separating operations. These are carried out mechanically, using differences in such physical characteristics of the refuse as size, density, and magnetic properties. Shredding or pulverizing reduces the size of the waste articles, resulting in a uniform mass of material. It is accomplished with hammer mills and rotary shredders.

1.0.13 DIGESTING & PROCESSING

Pulverized waste is ready for composting either by the open windrow method or in an enclosed mechanical facility. Windrows are long, low mounds of refuse. They are turned or mixed every few days to provide air for the microbes digesting the organics. Depending on moisture conditions, it may take five to eight weeks for complete digestion of the waste. Because of the metabolic action of aerobic bacteria, temperatures in an active compost pile reach about 65 °C (150 °F), killing pathogenic organisms that may be in the waste material.

Open windrow composting requires relatively large land areas. Enclosed mechanical composting facilities can reduce land requirements by about 85 percent. Mechanical composting systems employ one or more closed tanks or digesters equipped with rotating vanes that mix and aerate the shredded waste. Complete digestion of the waste takes about one week.

Digested compost must be processed before it can be used as a mulch or soil conditioner. Processing includes drying, screening, and granulating or pelletizing. These steps improve the market value of the compost, which is the most serious constraint to the success of composting as a waste management option. Agricultural demand for digested compost is usually low because of the high cost of transporting it and because of competition with inorganic chemical fertilizers.

1.0.14 SANITARY LAND FILL

Land disposal is the most common management strategy for municipal solid waste. Refuse can be safely deposited in a sanitary landfill, a disposal site that is carefully selected, designed, constructed, and operated to protect the environment and public health. One of the most important factors relating to landfilling is that the buried waste never comes in contact with surface water or groundwater. Engineering design requirements include a minimum distance between the bottom of the landfill and the seasonally high groundwater table. Most new landfills are required to have an impermeable liner or barrier at the bottom, as well as a system of groundwater-monitoring wells. Completed landfill sections must be capped with an impermeable cover to keep precipitation or surface runoff away from the buried waste. Bottom and

cap liners may be made of flexible plastic membranes, layers of clay soil, or a combination of both.[11]



Figure 1.1 Sanitary land fill (Source – Landfill Waste by Kenneth Westlake)

Daily cover soil may be available on-site, or it may be hauled in and stockpiled from off-site sources. Various types of heavy machinery, such as crawler tractors or rubber-tired dozers, are used to spread and compact the refuse and soil. Heavy steel-wheeled compactors may also be employed to achieve high-density compaction of the refuse. The area and depth of a new landfill are carefully staked out, and the base is prepared for construction of any required liner and leachate-collection system. Where a plastic liner is used, at least 30 cm (12 inches) of sand is carefully spread over it to provide protection from landfill vehicles. At sites where excavations can be made below grade, the trench method of construction may be followed.

1.0.15 CONSTRUCTING THE LANDFILL

The basic element of a sanitary landfill is the refuse cell. This is a confined portion of the site in which refuse is spread and compacted in thin layers. Several layers may be compacted on top of one another to a maximum depth of about 3 metres (10 feet). The compacted refuse occupies about one-quarter of its original loose volume. At the end of each day's operation, the refuse is covered with a layer of soil to eliminate windblown litter, odours, and insect or rodent problems. One refuse cell thus contains the daily volume of compacted refuse and soil cover. Several adjacent refuse cells make up a lift, and eventually a landfill may comprise two or more lifts stacked one on top of the other. The final cap for a completed landfill may also be covered with a layer of topsoil that can support vegetative growth.

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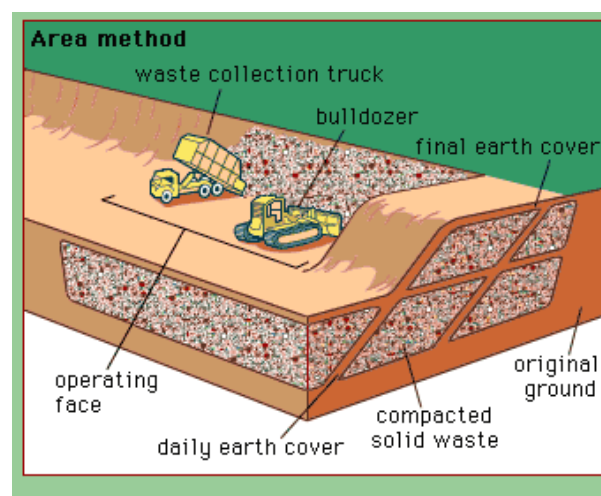


Figure 1.2 Construction of landfill fill (Source – landfill waste by Kenneth Westlake)

1.0.16 CONTROLLING BY PRODUCTS

Organic material buried in a landfill decomposes by anaerobic microbial action. Complete decomposition usually takes more than 20 years. One of the by-products of this decomposition is methane gas. Methane is poisonous and explosive when diluted in the air, and it is a potent greenhouse gas. It can also flow long distances through porous layers of soil, and, if it is allowed to collect in basements or other confined areas, dangerous conditions may arise. In modern landfills, methane movement is controlled by impermeable barriers and by gas-venting systems. In some landfills the methane gas is collected and recovered for use as a fuel, either directly or as a component of biogas.

A highly contaminated liquid called leachate is another by-product of decomposition in sanitary landfills. Most leachate is the result of runoff that infiltrates the refuse cells and comes in contact with decomposing garbage. If leachate reaches the groundwater or seeps out onto the ground surface, serious environmental pollution problems can occur, including the possible contamination of drinking-water supplies. Methods of controlling leachate include the interception of surface water in order to prevent it from entering the landfill and the use of impermeable liners or barriers between the waste and the groundwater. New landfill sites should also be provided with groundwater-monitoring wells and leachate-collection and treatment systems.[13]

1.0.17 IMPORTANCE IN WASTE MANAGEMENT

In communities where appropriate sites are available, sanitary landfills usually provide the most economical option for disposal of nonrecyclable refuse. However, it is becoming increasingly difficult to find sites that offer adequate capacity, accessibility, and environmental conditions. Nevertheless, landfills will always play a key role in solid-waste management. It is not possible to recycle all components of solid waste, and there will always be residues from incineration and other treatment processes that will eventually require disposal underground. In addition, landfills can actually improve poor-quality land. In some communities properly completed landfills are converted into recreational parks, playgrounds, or golf courses.

1.0.18 RECYCLING

Separating, recovering, and reusing components of solid waste that may still have economic value is called recycling. One type of recycling is the recovery and reuse of heat energy, a practice discussed separately in incineration. Composting can also be considered a recycling process, since it reclaims the organic parts of solid waste for reuse as mulch or soil conditioner. Still other waste materials have potential for reuse. These include paper, metal, glass, plastic, and rubber, and their recovery is discussed here.

1.0.19 SEPARATION

Before any material can be recycled, it must be separated from the raw waste and sorted. Separation can be accomplished at the source of the waste or at a central processing facility. Source separation, also called curbside separation, is done by individual citizens who collect newspapers, bottles, cans, and garbage separately and place them at the curb for collection. Many communities allow “commingling” of nonpaper recyclables (glass, metal, and plastic). In either case, municipal collection of source-separated refuse is more expensive than ordinary refuse collection.[14]

In lieu of source separation, recyclable materials can be separated from garbage at centralized mechanical processing plants. Experience has shown that the quality of recyclables recovered from such facilities is lowered by contamination with moist garbage and broken glass. The best practice, as now recognized, is to have citizens separate refuse into a limited number of categories, including newspaper; magazines and other wastepaper; commingled metals, glass, and plastics; and garbage and other nonrecyclables. The newspaper, other paper wastes, and commingled recyclables are collected separately from the other refuse and are processed at a centralized material recycling facility, or MRF (pronounced “murf” in waste-management jargon). A modern MRF can process about 300 tons of recyclable wastes per day.

At a typical MRF, commingled recyclables are loaded onto a conveyor. Steel cans (“tin” cans are actually steel with only a thin coating of tin) are removed by an electromagnetic separator, and the remaining material passes over a vibrating screen in order to remove broken glass. Next, the conveyor passes through an air classifier, which separates aluminium and plastic containers from heavier glass containers. Glass is manually sorted by colour, and aluminium cans are separated from plastics by an eddy-current separator, which repels the aluminium from the conveyor belt.[15]

1.0.20 REUSE

Recovered broken glass can be crushed and used in asphalt pavement. Colour-sorted glass is crushed and sold to glass manufacturers as cullet, an essential ingredient in glassmaking. Steel cans are baled and shipped to steel mills as scrap, and aluminium is baled or compacted for reuse by smelters. Aluminium is one of the smallest components of municipal solid waste, but it has the highest value as a recyclable material. Recycling of plastic is a challenge, mostly because of the many different polymeric materials used in its production. Mixed thermoplastics can be used only to make lower-quality products, such as “plastic lumber.”

In the paper stream, old newspapers are sorted by hand on a conveyor belt in order to remove corrugated materials and mixed papers. They are then baled or loose-loaded into trailers for shipment to paper mills, where they are reused in the making of more newspaper. Mixed paper is separated from corrugated paper for sale to tissue mills. Although the processes of pulping, de-inking, and screening wastepaper are generally more expensive than making paper from virgin wood fibres, the market for recycled paper has grown with the establishment of more processing plants.

Rubber is sometimes reclaimed from solid waste and shredded, reformed, and remoulded in a process called re vulcanisation, but it is usually not as strong as the original material. Shredded rubber can be used as an additive in asphalt pavements and artificial turf and is also sold directly as an outdoor mulch. Discarded tires may be employed as swings and other recreational structures for use by children in “tire playgrounds.”

In general, the most difficult problem associated with the recycling of any solid-waste material is finding applications and suitable markets. Recycling by itself will not solve the growing problem of solid-waste management and disposal. There will always be some unusable and completely valueless solid residue requiring final disposal.

1.1 CLASSIFICATION OF SOLID WASTES:

Solid wastes are the organic and inorganic waste materials such as product packaging, grass clippings, furniture, clothing, bottles, kitchen refuse, paper, appliances, paint cans, batteries, etc., produced in a society, which do not generally carry any value to the first user(s). Solid wastes, thus, encompass both a heterogeneous mass of wastes from the urban community as well as a more homogeneous accumulation of agricultural,

industrial and mineral wastes. While wastes have little or no value in one setting or to the one who wants to dispose them, the discharged wastes may gain significant value in another setting. Knowledge of the sources and types of solid wastes as well as the information on composition and the rate at which wastes are generated/ disposed is, therefore, essential for the design and operation of the functional elements associated with the management of solid wastes.

Solid wastes are classified on the basis of source of generation and type, which will explain in Subsections 1.1.11.1d 1.1.2, respectively.

1.1.1 SOURCE-BASED CLASSIFICATION:

Historically, the sources of solid wastes have been consistent, dependent on sectors and activities (Tchobanoglous, et al., 1977), and these include the following:

- i. **RESIDENCIAL:** This refers to wastes from dwellings, apartments, etc., and consists of leftover food, vegetable peels, plastic, clothes, ashes, etc.
- ii. **COMMERCIAL:** This refers to wastes consisting of leftover food, glasses, metals, ashes, etc., generated from stores, restaurants, markets, hotels, motels, auto-repair shops, medical facilities, etc.
- iii. **INSTITUTIONAL:** This mainly consists of paper, plastic, glasses, etc., generated from educational, administrative and public buildings such as schools, colleges, offices, etc.
- iv. **MUNICIPAL:** This includes dust, leafy matter, building debris, treatment plant residual sludge, etc., generated from various municipal activities like construction and demolition, street cleaning, landscaping, etc. (Note, however, in India municipal can typically subsume items at (i) to (iii) above).
- v. **INDUSTRIAL:** This mainly consists of process wastes, ashes, demolition and construction wastes, hazardous wastes, etc., due to industrial activities.
- vi. **AGRICULTURAL:** This mainly consists of spoiled food grains and vegetables, agricultural remains, litter, etc., generated from fields, orchards, vineyards, farms, etc.
- vii. **OPEN AREAS:** this includes wastes from areas such as Streets, alleys, parks, vacant lots, playgrounds, beaches, highways, recreational areas, etc.

1.1.2 TYPE-BASED CLASSIFICATION:

Classification of wastes based on types, i.e., physical, chemical, and biological characteristics of wastes, is as follows (Phelps et al., 1995):

- (i) **GARBAGE:** This refers to animal and vegetable wastes resulting from the handling, sale, storage, preparation, cooking

and serving of food. Garbage comprising these wastes contains putrescible (rotting) organic matter, which produces an obnoxious odour and attracts rats and other vermin. It, therefore, requires special attention in storage, handling and disposal.

- (ii) **ASHES AND RESIDUES:** These are substances remaining from the burning of wood, coal, charcoal, coke and other combustible materials for cooking and heating in houses, institutions and small industrial establishments. When produced in large quantities, as in power-generation plants and factories, these are classified as industrial wastes. Ashes consist of fine powdery residue, cinders and clinker often mixed with small pieces of metal and glass. Since ashes and residues are almost entirely inorganic, they are valuable in landfills.
- (iii) **COMBUSTIBLE & NON COMBUSTIBLE WASTE:** These consist of wastes generated from households, institutions, commercial activities, etc., excluding food wastes and other highly putrescible material. Typically, while combustible material consists of paper, cardboard, textile, rubber, garden trimmings, etc., non-combustible material consists of such items as glass, crockery, tin and aluminium cans, ferrous and non-ferrous material and dirt.
- (iv) **BULKY WASTE:** These include large household appliances such as refrigerators, washing machines, furniture, crates, vehicle parts, tyres, wood, trees and branches. Since these household wastes cannot be accommodated in normal storage containers, they require a special collection mechanism.
- (v) **STREET WASTE:** These refer to wastes that are collected from streets, walkways, alleys, parks and vacant plots, and include paper, cardboard, plastics, dirt, leaves and other vegetable matter. Littering in public places is indeed a widespread and acute problem in many countries including India, and a solid waste management system must address this menace appropriately)
- (vi) **BIO DEGRADABLE & NON BIO DEGRADABLE WASTE:** Biodegradable wastes mainly refer to substances consisting of organic matter such as leftover food, vegetable and fruit peels, paper, textile, wood, etc., generated from various household and industrial activities. Because of the action of micro-organisms, these wastes are degraded from complex to simpler compounds. Non - biodegradable wastes consist of inorganic and recyclable materials such as plastic, glass, cans, metals, etc.
- (vii) **DEAD ANIMALS:** With regard to municipal wastes, dead animals are those that die naturally or are accidentally killed on the road. Note that this category does not include carcasses and animal parts from slaughter-houses, which are regarded as industrial wastes. Dead animals are divided into two groups - large and small. Among the large animals are horses, cows,

- goats, sheep, pigs, etc., and among the small ones are dogs, cats, rabbits, rats, etc.
- (viii) The reason for this differentiation is that large animals require special equipment for collection .If not collected promptly, dead animals pose a threat to public health since they attract flies and other vermin as they decay. Their presence in public places is particularly offensive from the aesthetic point of view as well.
 - (ix) **ABANDONED VEHICLES:** This category includes automobiles, trucks and trailers that are abandoned on streets and other public places. However, abandoned vehicles have significant scrap value for their metal, and their value to collectors is highly variable.
 - (x) **CONSTRUCTION & DEMOLITION WASTE:** These are wastes generated as a result of construction, refurbishment, repair and demolition of houses, commercial buildings and other structures. They consist mainly of earth, stones, concrete, bricks, lumber, roofing and plumbing materials, heating systems and electrical wires and parts of the general municipal waste stream.
 - (xi) **FARM WASTE:** These wastes result from diverse agricultural activities such as planting, harvesting, production of milk, rearing of animals for slaughter and the operation of feedlots. In many areas, the disposal of animal waste has become a critical problem, especially from feedlots, poultry farms and dairies.
 - (xii) **HAZARDOUS WASTE:** Hazardous wastes are those defined as wastes of industrial, institutional or consumer origin that are potentially dangerous either immediately or over a period of time to human beings and the environment. This is due to their physical, chemical and biological or radioactive characteristics like ignitability, corrosivity, reactivity and toxicity. Note that in some cases, the active agents may be liquid or gaseous hazardous wastes. These are, nevertheless, classified as solid wastes as they are confined in solid containers. Typical examples of hazardous wastes are empty containers of solvents, paints and pesticides, which are frequently mixed with municipal wastes and become part of the urban waste stream. Certain hazardous wastes may cause explosions in incinerators and fires at landfill sites. Others such as pathological wastes from hospitals and radioactive wastes also require special handling. Effective management practices should ensure that hazardous wastes are stored, collected, transported and disposed of separately, preferably after suitable treatment to render them harmless.
 - (xiii) **SEWAGE WASTE:** The solid by-products of sewage treatment are classified as sewage wastes. They are mostly organic and derived from the treatment of organic sludge separated from both raw and treated sewages. The inorganic fraction of raw sewage such as grit and eggshells is separated at the preliminary stage of treatment, as it may entrain putrescible organic matter

with pathogens and must be buried without delay. The bulk of treated, dewatered sludge is useful as a soil conditioner but is invariably uneconomical. Solid sludge, therefore, enters the stream of municipal wastes, unless special arrangements are made for its disposal.

1.2 ENERGY HARVESTING FROM MUNICIPAL SOLID WASTE:

Municipal Solid Waste (MSW) contains organic as well as inorganic matter. The latent energy present in its organic fraction can be recovered for gainful utilisation through adoption of suitable Waste Processing and Treatment technologies.

The recovery of energy from wastes also offers a few additional benefits as follows:

- (i) The total quantity of waste gets reduced by nearly 60% to over 90%, depending upon the waste composition and the adopted technology;
- (ii) Demand for land, which is already scarce in cities, for land filling is reduced;
- (iii) The cost of transportation of waste to far-away land fill sites also gets reduced proportionately;
- (iv) Net reduction in environmental pollution (by reducing the CH₄ emission in the air).

It is, therefore, only logical that, while every effort should be made in the first place to minimise generation of waste materials and to recycle and reuse them to the extent feasible, the option of Energy Recovery from Wastes be also duly examined. Wherever feasible, this option should be incorporated in the over-all scheme of Waste Management.

1.3 BASIC TECHNIQUES OF ENERGY HARVESTING:

Energy can be recovered from the organic fraction of waste (biodegradable as well as non-biodegradable) basically through two methods as follows:

- (i) Thermo-chemical conversion : This process entails thermal de-composition of organic matter to produce either heat energy or fuel oil or gas.

The Thermo-chemical conversion processes are useful for wastes containing high percentage of organic non-biodegradable matter and low moisture content. The main technological options under this category include Incineration and Pyrolysis/ Gasification.

- (ii) Bio-chemical conversion: This process is based on enzymatic decomposition of organic matter by microbial action to produce methane gas or alcohol.

The bio-chemical conversion processes, on the other hand, are preferred for wastes having high percentage of organic bio-degradable (putrescible) matter and high level of moisture/ water content, which aids microbial activity. The main technological option under this category is Anaerobic Digestion, also referred to as Bio methanation.

1.4 PARAMETERS AFFECTING ENERGY RECOVERY:

The main parameters which determine the potential of Recovery of Energy from

Wastes (including MSW), are: ·

- Quantity of waste, and
- Physical and chemical characteristics (quality) of the waste.

The actual production of energy will depend upon specific treatment process employed, the selection of which is also critically dependent upon the above two parameters.

The important physical parameters requiring consideration include:

- Size of constituents: Smaller size of the constituents aids in faster decomposition of the waste.
- Density: Wastes of the high density reflect a high proportion of biodegradable organic matter and moisture. Low density wastes, on the other hand, indicate a high proportion of paper, plastics and other combustibles.
- Moisture content: High moisture content causes biodegradable waste fractions to decompose more rapidly than in dry conditions. It also makes the waste rather unsuitable for thermo-chemical conversion (incineration, pyrolysis/gasification) for energy recovery as heat must first be supplied to remove moisture.

The important chemical parameters to be considered for determining the energy recovery potential and the suitability of waste treatment through bio- chemical or thermo-chemical conversion technologies include :-

- Volatile solids
- Fixed carbon content
- Inerts
- Calorific value
- CIN ratio (carbon/nitrogen ratio)
- Toxicity
- Chemical Oxygen Demand

1.5 ASSESSMENT OF ENERGY RECOVERY POTENTIAL FROM THERMO-CHEMICAL CONVERSION AND BIO-CHEMICAL CONVERSION:

An assessment of the potential of recovery of energy from MSW through different treatment methods carried out in Municipal Solid Waste Management ,C.P.H.E.E.O. manual, from the knowledge of its calorific value and organic fraction, as under:

In thermo-chemical conversion all of the organic matter, biodegradable as well as non - biodegradable, contributes to the energy output:

Total waste quantity : W tonnes

Net Calorific Value : NCV k-cal/kg.

Energy recovery potential (kWh) = $NCV \times W \times 1000/860 = 1.16 \times NCV \times W$

Power generation potential (kW) = $1.16 \times NCV \times W/24 = 0.048 \times NCV \times W$

Conversion Efficiency = 25%

Net power generation potential (kW) = $0.012 \times NCV \times W$ If NCV = 1200 k-cal/kg.,
then, **Net power generation potential (kW) = $14.4 \times W$**

In bio-chemical conversion, only the biodegradable fraction of the organic matter can contribute to the energy output:

Total waste quantity: W (tons)

Total Organic / Volatile Solids: VS == 50 %, say

Organic bio-degradable fraction: approx.

66% of VS == $0.33 \times W$ Typical digestion

efficiency = 60 %

Typical bio-gas yield: B (m³) = 0.80 m³/kg. of VS destroyed = $0.80 \times 0.60 \times 0.33 \times W$
 $\times 1000$

= $L \times 58.4 \times W$

Calorific Value of bio-gas = 5000 kcal/m³ (typical)

Energy recovery potential (kWh) = B x

$5000/860 = 921 \times W$ Power generation

potential (kW) = $92 L \times W/24 = 38.4 \times W$

Typical Conversion Efficiency = 30%

Net power generation potential (kW) = $11.5 \times W$

In general, 100 tonnes of raw MSW with 50-60% organic matter can generate about 1- 1.5 Mega Watt power, depending upon the waste characteristics.

1.6 TECHNOLOGICAL OPTIONS:

1.6.1 PYROLYSIS/GASIFICATION:

Pyrolysis is a process of chemical decomposition of organic matter brought about by heat. In this process, the organic material is heated in absence of air until the molecules thermally break down to become a gas comprising smaller molecules (known collectively as syngas).

Gasification can also take place as a result of partial combustion of organic matter in presence of a restricted quantity of oxygen or air. The gas so produced is known as producer gas. The gases produced by

pyrolysis mainly comprise carbon monoxide (25%), hydrogen and hydrocarbons (15%), and carbon dioxide and nitrogen (60%). The next step is to 'clean' the syngas or producer gas. Thereafter, the gas is burned in internal combustion (IC) engine generator sets or turbines to produce electricity.[16]

1.6.2 COMBUSTION/INCINERATION:

In this process, wastes are directly burned in presence of excess air (oxygen) at high temperatures (about 800°C), liberating heat energy, inert gases, and ash. Combustion results in transfer of 65%-80% of heat content of the organic matter to hot air, steam, and hot water. The steam generated, in turn, can be used in steam turbines to generate power.

1.6.3 LANDFILL GAS RECOVERY:

The waste dumped in a landfill becomes subjected, over a period of time to anaerobic conditions. As a result, its organic fraction slowly volatilizes and decomposes, leading to production of 'landfill gas', which contains a high percentage of methane (about 50%). It can be used as a source of energy either for direct heating/ cooking applications or to generate power through IC engines or turbines.

The amount of market waste, mostly vegetable market waste, generation in Kolkata has been estimated to be 1093 ton/day, followed by household waste which is 1028 ton/day. Both these fractions of the municipal solid waste contain a considerable proportion of biodegradable organic matter and when dumped into the land fill sites, decompose biochemically in presence of anaerobic bacteria to produce landfill gas (LFG), a renewable energy source. Landfill gas contributes to global warming due to uncontrolled emission of CH₄ and CO₂ into the atmosphere from the landfill sites, apart from other environmental hazards, like ground water contamination and soil pollution due to percolation of leachate. According to a study carried out in the year 2011, it had been estimated that 6.19x10⁶ to 7.53x10⁶ m³ of landfill gas is generated per year from the Dhapa landfill site in Kolkata equivalent to an annual energy generation rate of 2.96 x 10⁶ to 3.6 x 10⁶ m³

1.6.4 ANAEROBIC DIGESTION / BIOMETHANATION:

In this process, the organic fraction of the waste is segregated and fed into a closed container (biogas digester). In the digester, the segregated waste undergoes biodegradation in presence of methanogenic bacteria

and under anaerobic conditions, producing methane-rich biogas and effluent. The biogas can be used either for cooking/heating applications, or for generating motive power or electricity through dual- fuel or gas engines, low-pressure gas turbines, or steam turbines. The sludge from anaerobic digestion, after stabilization, can be used as a soil conditioner. It can even be sold as manure depending upon its composition, which is determined mainly by the composition of the input waste.[17]

Table 1.1 :advantages and disadvantages of different technological options

Technological option	Advantages	Disadvantages
Pyrolysis/Gasification	Production of fuel gas/oil, which can be used for a variety of applications. Compared to incineration, control of atmospheric pollution can be dealt with in a superior way, in techno-economic sense.	Net energy recovery may suffer in case of wastes with excessive moisture. High viscosity of pyrolysis oil may be problematic for its transportation and burning.
Combustion/Incineration	Most suitable for high calorific Value waste, pathological wastes, etc. Low land area requirement. Can be located within city limits, reducing the cost of waste transportation. Thermal energy recovery for direct heating for power generation.	Least suitable for aqueous / high moisture content / low Calorific value and chlorinated waste. Excessive moisture and inert content affects net energy recovery, auxiliary fuel support may be required to sustain combustion .Concern for metals that may Concentrate in ash, emission of particulars, SO _x , NO _x chlorinated compounds. High Capital and O&M costs. Skilled personnel required. Overall efficiency is low for small power station.

Landfill Gas recovery	Least cost option. The gas produced can be utilized for power generation or as domestic fuel for direct thermal applications. Highly skilled personnel not necessary. Natural resources re returned to soil and recycled. Can convert lower lying marshy land to useful areas.	Soil/ground water aquifer may get contaminated by polluted leachate treatment system. Inefficient gas recovery process yielding 30-40% of total gas generation. Large land area requirement. Spontaneous ignition explosions due to possible Build up of methane Concentrations in atmosphere.
Anaerobic Digestion / Biomethanation	Every recovery with production of high grade soil conditioner. No power requirement unlike aerobic composting where sieving and turning of waste pile for supply of oxygen is necessary. Enclosed system enables all the gas produced to be collected for use. Controls green house gases emission. Free from bad odours, rodent and fly menace, visible pollution and soil resistance. Can be done at small scale.	Unsuitable for wastes having less organic matter. Requires waste segregation for improving digestion efficiency. Heat released is less resulting in lower and less effective destruction of pathogenic organism that in aerobic composting. However now thermophilic Temperature systems are also available to take care of this.

Table 1.2 :desirable range of important waste parameters (source: municipal solid waste management manual, ministry of urban development, govt. of india)

Waste Treatment Method	Basic principle	Important Waste Parameters	Desirable Range
<u>Thermo-Chemical Conversion</u> - Incineration - Pyrolysis - Gastification	Decomposition of organic matter by action of heat.	Moisture Content	<45%
		Organic/Volatile matter	> 40%
		Fixed Carbon	< 15%
		Calorific Value (Net Calorific Value)	>1200 kcal/kg
<u>Bio-chemical conversion</u> Anaerobic Digestion/Bio methanation	Decomposition of organic matter by microbial action.	Moisture content	> 50%
		Organic/Volatile matter	> 40%
		C/N ratio	25-30

1.7 WASTE TREATMENT: HOW TO SELECT APPROPRIATE TECHNOLOGIES

Most digesters installed in the field lack mechanisms for temperature control and removal of dissolved oxygen. Hence, efficiency of these digesters is reported to be low, particularly during the winter months. There are different temperature ranges during which mesophilic and thermophilic bacteria are most active causing maximum gas yield. Generally, mesophilic bacteria are most active in the temperature range 30-40°C and thermophilic bacteria in the range 50-60°C. Choice between the mesophilic and thermophilic fermentations is governed by the natural climatic conditions in which the plant is located. Though, it is possible to create conditions for thermophilic fermentation by external heat, but such a method is generally uneconomical. Length of fermentation period is linked with the digester temperature. The methanogens are inactive in extreme high and low temperatures, while the optimum temperature is 35°C. When the ambient temperature decreases to 10°C, gas production virtually stops. The selection and adoption of MSW processing technologies should be based on defined selection criteria and be subject to a detailed due diligence study, which ascertains the appropriateness of the technology to the prevailing conditions of the respective ULB. ULBs might even acquire external expertise, to find the most viable solution among complex technologies. Relevant selection criteria are listed in Table I-C and applied to a number of common strategies and technology options. The financial implication of segregation on processing/treatment costs is substantial and should be considered before selecting any processing/ treatment technology. Treatment/processing of segregated waste streams not only reduce operational costs but also increases the efficiency of the process. According to **Municipal Solid Waste Management Manual (part I)** gives some indicative criteria as follows:-

Table 1.3 : Indicative Criteria for Selection of Appropriate Technology or Combination of Technologies
(SOURCE : Municipal Solid Waste Management manual, Ministry of urban Development, Government of India)

CRITERIA	WINDROW COPOSING	VERMICULTURE	BIOMEWTHANATION	INCINERATION	SANITARY LANDFILL
Facility Location	To be located as per the buffer zone criteria mentioned below.	To be located as per the buffer zone criteria mentioned below.	To be located as per the buffer zone criteria mentioned below.	To be located as per the buffer zone criteria mentioned below.	Landfill sites must be located at least 500m away from residential areas and should abide by the criteria mentioned in SWM Rules and state level guidelines.
Land Requirement	For 300 TPD of segregated pre-sorted MSW : 5 ha of land including buffer zone is required.	For 20 TPD of segregated / pre- sorted 1.25 ha	For 300 TPD of segregated / pre-sorted MSW: 2.5 ha of land is required.	For 100 TPD of mixed waste : 5 ha of land including buffer zone.	For 300 TPD of MSW : 300 ha of land is required for 20 years
Natural environment	Composition in coastal high rain-fall areas should have a shed to prevent waster from becoming excessively wet and thereby to control leachate generation	Composting in coastal / high rain fall should have a shed to prevent waster from becoming excessive wet and thereby to control leachate generation			Should be avoided in marshy land and in conditions where the ground water table is 2 m from the base of the liner. In marshy land apart from ground and surface water contamination potential, there could be huge risks due structural safety of the landfill (slippage and complete breakdown)

Table 1.3 (Continued)

CRITERIA	WINDOWROW COPOSITING	VERMICULTURE	BIOMEWTHANATI ON	INCINERATION	SANITARY LANDFILL
Requirement for Segregation prior to Technology	High	Very high	Very high	High – Feed stock should be free from inerts and low on moisture content	Only inert waste may be placed in landfills as per SWM Rule, 2015
Waste Quantity which can be managed by a single Facility	20 TPD and above	1 TPD to 20 TPD Higher capacities can also be planned if adequate land is available along with other necessary arrangements	1 TPD at small scale to 500 TPD at larger scale.	1000 TPD and above of mixed waste (smaller plants are not Technologically viable given the cost of required environmental control equipment and boiler technology.	100 TPD inert and above. Smaller landfills are not technoeconomically viable
Technology Maturity	Window com-positing technique is well established	Community scale projects are successful	Feasibility for biodegradable waste is proven. In case of mixed waste appropriate pre-sorting has to be carried out.	Technology is available. However constraints of low calorific value, high moisture content and high proportion of inert waste should be considered while undertaking the project commercially.	Sanitary landfill is a proven method for safe disposal of waste, practices world. Over. However it has environmental implications and efforts have to be made to minimize waste going to landfills. Rules, 2015 only permit inert waste to be land filled.

1.8 ANAEROBIC DIGESTION (AD):

In this process, also referred to as bio-methanation, the organic fraction of wastes is segregated and fed to a closed container (biogas digester) where, under anaerobic conditions (in absence of oxygen), the organic wastes undergo bio-degradation producing methane-rich biogas and effluent/ sludge.

The biogas production ranges from 50-150 m³/tonne of wastes, depending upon the composition of waste.(Manual on "Municipal Solid Waste Management", C.P.H.E.E.O.) The biogas can be utilised either for cooking/ heating applications, or through dual fuel or gas engines or gas steam turbines for generating motive power or electricity. The sludge from anaerobic digestion, after stabilisation, can be used as a soil conditioner, or even sold as manure depending upon its composition, which is determined mainly by the composition of the input waste.[18]

1.8.1 DEFINITION OF BIOGAS:

Biogas is a form of renewable energy produced from organic matter through a biological process . It is typically derived from anaerobic digestion

diverse range of organic feedstocks including biomass, sewage, agricultural waste, certain industrial wastes (e.g. from the food and beverage manufacturing sector) and municipal waste.

1.8.2 TYPICAL COMPOSITION OF BIOGAS:

Composition of biogas depends upon feed material also. Biogas is about 20% lighter than air has an ignition temperature in range of 65°C to 75°C. An odourless and colourless gas that burns with blue flame similar to LPG gas. Its caloric value is 20 Mega Joules (MJ) /m³ and it usually burns with 60 % efficiency in a conventional biogas stove. This gas is useful as fuel to substitute firewood, cow-dung, petrol, LPG, diesel, and electricity, depending on the nature of the task, and local supply conditions and constraints. Biogas digester systems provide a residue organic waste, after its anaerobic digestion(AD) that has superior nutrient qualities over normal organic fertilizer, as it is in the form of ammonia and can be used as manure. Anaerobic biogas digesters also function as waste disposal systems, particularly for human wastes, and can, therefore, prevent potential sources of environmental contamination and the spread of pathogens and disease causing bacteria. Biogas technology is particularly valuable in agricultural residual treatment of animal excreta and kitchen refuse (residuals).

Table 1.4 :Typical composition of Biogas

Component	Concentration (by volume)
Methane (CH ₄)	55 – 60%
Carbon dioxide (CO ₂)	35 – 40%
Water (H ₂ O)	2 – 7%
Hydrogen Sulphide (H ₂ S)	2%
Ammonia (NH ₃)	0 – 0.05%
Nitrogen (N ₂)	0 – 2%
Oxygen (O ₂)	0 – 2%
Hydrogen (H ₂)	0 – 1%

1.8.3 UTILIZATION OF BIOGAS:

- **Cooking:** Biogas can be used in a specially designed burner for cooking purpose. Biogas consumption is taken as 0.25m³/person/day. So, a biogas plant of 2 cubic meters capacity is sufficient for providing cooking fuel needs of a family of about five to six persons .
- **Lighting:** Biogas is used in silk mantle lamps for lighting purpose. The requirement of gas for powering a 100 candle lamp is 0.13 m³/ hour.
- **Power generation:** Biogas can be used to operate a dual fuel engine to replace up to 80% of diesel oil. Diesel engines have been modified to run 100 percent on biogas.
- **Transport fuel:** After removal of CO₂, H₂S and water vapour biogas can be converted to natural gas quality for use in vehicles.

1.8.4 COMPARISON OF THE QUALITY OF BIOGAS EQUIVALENT TO OTHER HYDROCARBON FUELS:

Quantities of various hydrocarbon fuels that will have energy equivalent to 1 m³ of biogas are given in as under :-

Name of the fuel oil	Kerosene	Firewood	Cow dung	Charcoal	Furnace	Electricity	LPG
Equivalent quantity to 1m³ of biogas	0.60 lit	3.50 kg.	12.3 Kg	1.50 Kg	0.40 lit.	4.70 kWh	0.45 kg

1.8.5 BTOGAS POTENTIAL IN INDIA:

The bio-energy potential from municipal solid waste, crop residue and agricultural waste, wastewater sludge, animal manure, industrial waste which includes distilleries, dairy plants, pulp and paper, poultry, slaughter houses, sugar industries is estimated. The total potential of biogas from all the above sources excluding wastewater has been estimated to be 40,734 Mm³/year [6].

In India, energy demand from various sectors is increased substantially and the energy supply is not in pace with the demand which resulted in a deficit of 11,436 MW, which is equivalent to 12.6 % [6] of peak demand in 2006. The total installed capacity of bio-energy generation till 2007 from solid biomass and waste to energy is about 1,227 MW against a potential of 25,700 MW.

1.8.6 FACTORS AFFECTING YIELD AND PRODUCTION OF BIOGAS:

1.8.6.1 Carbon/Nitrogen (C/N) Ratio:

The relationship between the amount of carbon and nitrogen present in organic materials is expressed by the carbon/nitrogen (C/N) ratio. A suitable C/N ratio plays an important role for the proper proliferation of the bacteria for the degradation process. Depending upon the relative richness in carbon and nitrogen content, feed material can be classified as nitrogen or carbon-rich. It is generally found that during digestion, micro-organisms utilise carbon 25 to 30 times faster than nitrogen, i.e. carbon content in feedstock should be 25 to 30 times of the nitrogen content. To meet this requirement, constituents of feedstock are chosen in such a way to ensure a C/N ratio of 25:1 to 30:1 and concentration of dry matter as 7- 10%. Even in situations where C/N ratio is close to 30: 1, the biomass can undergo efficient anaerobic fermentation only if waste materials are also biodegradable at the same time.

1.8.6.2 Temperature :

Most digesters installed in the field lack mechanisms for temperature control and removal of dissolved oxygen. Hence, efficiency of these digesters is reported to be low, particularly during the winter months. There are different temperature ranges during which mesophilic and thermophilic bacteria are most active causing maximum gas yield. Generally, mesophilic bacteria are most active in the temperature range 30-40°C and thermophilic bacteria in the range 50-60°C. Choice between the mesophilic and thermophilic fermentations is governed by the natural climatic conditions in which the plant is located. Though, it is possible to create conditions for thermophilic fermentation by external heat, but such a method is generally uneconomical. Length of fermentation period is linked with the digester temperature. The methanogens are inactive in extreme high and low temperatures, while the optimum temperature is 35°C. When the ambient

temperature decreases to 10°C, gas production virtually stops. Satisfactory gas production takes place in the mesophilic range (30-40°C). Proper insulation of digester helps to increase gas production during the cold weather. When the digester operates at a temperature of 15°C it takes nearly a year for the digestion cycle to complete. However, if the temperature is approximately 35°C, the cycle can be easily completed in less than a month. When the digester temperature is maintained at 25°C, it takes approximately 50 days for digestion of cattle waste. But, if the temperature ranges between 32 and 38°C, digestion is complete within 28 days. The average minimum ambient temperature in north-eastern India falls below 13.5°C during the winter season, which lasts for about 4-5 months in a year. Further, temperatures during the day and night differ significantly in this region. The bacteria cannot survive under such extreme temperature variations as well as at low temperature.

1.8.6.3 pH Value:

It is essentially a measure of the acidity and alkalinity of a solution before feeding to a digester. A pH value of 7 is regarded as neutral, less than 7 as acidic and more than 7 as alkaline. Augenstein et al. suggested that during anaerobic fermentation, micro-organisms require a natural or mildly alkaline environment for efficient gas production. An optimum biogas production is achieved when the pH value of input mixture in the digester is between

6.25 and 7.50. The pH value in a biogas digester is also a function of the retention time. In the initial period of fermentation, as large amounts of organic acids are produced by acid forming bacteria, the pH value inside the digester can decrease below 5. This inhibits or even stops the digestion or fermentation process. Methanogenic bacteria is very sensitive to pH value and do not thrive below a value of 6.5. Later, as the digestion process continues, concentration of NH_4 increases due to the digestion of N_2 , which can increase the pH value to above 8. When the CH_4 production level is stabilized, the pH range remains between 7.2 and 8.2. According to studies in China, during the period when ambient temperature varies between 22 and 26°C, it takes approximately 6 days for pH value to acquire a stable value.

1.8.6.4 Dilution and Consistency of Input:

All waste materials fed to a biogas plant consist of solid substance-volatile organic matter and non-volatile matter (fixed solids)-and water. During anaerobic fermentation process, volatile solids undergo digestion and non-volatile solids remain unaffected. According to a finding by The Energy and Resources Institute (TERI), fresh cattle waste consists of approximately 20% total solid (TS) and 80% water. TS, in turn, consists of 70% volatile solids and 30% fixed solid. For optimum gas yield through anaerobic fermentation, normally, 8-10% TS in feed is required [30]. This is achieved by making slurry of fresh cattle dung in water in the ratio of

1.1. However, if the dung is in dry form, the quantity of water has to be increased accordingly to arrive at the desired consistency of the input (i.e., ratio could vary from 1:1.25 to even 1:2). If the dung is too diluted, the solid particles will settle down into the digester and if it is too thick, the particles impede the flow of the gas formed at the lower part of the digester. In both cases, gas production will be less than optimum. It is also necessary to remove inert materials such as stones from the inlet before feeding the slurry into the digester. Otherwise, the effective volume of digester will decrease.

1.8.6.5 Loading Rate:

Loading rate is defined as the amount of raw materials fed per day per unit volume of digester capacity. It is an important parameter that affects gas yield. If the plant is overfed, acids will accumulate and methane production will be inhibited since micro-bacteria cannot survive in acidic situation. Similarly, if the plant is underfed, the gas production will also be low because of alkaline solution, which is also not a favourable condition for anaerobic bacteria.

1.8.6.6 Hydraulic Retention Time:

Hydraulic retention time (HRT) is the average period that a given quantity of input material remains in the digester to be acted upon by the methanogens. In a cattle-dung plant, the retention time is calculated by dividing total volume of the digester by volume of input added daily. From the results of experiments at ITT Guwahati it is observed that the rate of gas generation is initially high and then, gradually, declines as the digestion approaches completion. Thus, the time required for 70-80% digestion is considerably less than that needed to achieve complete digestion. HRT is chosen to achieve at least 70-80% digestion. Langrange suggested that HRT depends upon the interior temperature of the digester- higher the temperature of the digester lower the retention time. HRT varies between 20 and 120 days, depending upon the design and operating temperature of the digester.

1.8.6.7 Toxicity:

Mineral ions, heavy metals and detergents are some toxic materials that inhibit the normal growth of pathogens in the digester. Small quantity of mineral ions (e.g., sodium, potassium, calcium, magnesium, ammonium and sulphur) also stimulates the growth of bacteria, while very heavy concentration of these ions leads to toxic effects. For example, presence of NH_4 from 50 to 200 mg/l stimulates the growth of anaerobic microbes, whereas, its concentration above 1500 mg/l produces toxicity. Similarly, heavy metals such as copper, nickel, chromium, zinc, lead etc., in small quantities are essential for the growth of bacteria but their higher concentration has toxic effects. Detergents including soap, antibiotics, organic solvents etc. also inhibit the activity of methane producing bacteria and hence addition of these substances in the digester should be avoided.

1.8.6.8 Agitation:

Agitation or mixing of digester contents significantly helps to ensure intimate contact between micro-organisms, which leads to improved fermentation efficiency.

It is suggested that effect of varying degrees of mixing of digester contents improves biogas production. The major problem associated with the different designs of biogas plant such as KVIC, Deen- bandhu etc. is that a thick layer of scum formation appears at the top of the digester which blocks the gas from coming out of the upper free portion of the digester. Thus, no gas is available at the utility point.

1.8.7 PRINCIPLES FOR PRODUCTION OF BIOGAS:

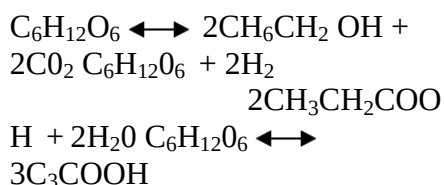
Organic substances exist in wide variety from living beings to dead organisms. Organic matters are composed of Carbon (C), combined with elements such as Hydrogen (H), Oxygen (O), Nitrogen (N), Sulphur (S) to form variety of organic compounds such as carbohydrates, proteins and lipids. In nature MOs (microorganisms), through digestion process breaks the complex carbon into smaller substances.

Biological process involving in the formation of biogas:

1. HYDROLYSIS
2. ACIDIFICATION
3. METHANOGENESIS

HYDROLYSIS: In the first step the organic matter is enzymolysed externally by extracellular enzymes, cellulose, amylase, protease and lipase of microorganisms. Bacteria decompose long chains of complex carbohydrates, proteins and lipids into small chains. For example, Polysaccharides are converted into monosaccharide. Proteins are split into peptides and amino acids.

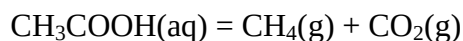
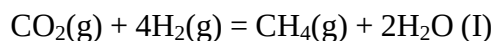
ACIDIFICATION: Acid-producing bacteria, involved this step, convert the intermediates of fermenting bacteria into acetic acid, hydrogen and carbon dioxide. These bacteria are anaerobic and can grow under acidic conditions. To produce acetic acid, they need oxygen and carbon. For this, they use dissolved O_2 or bounded-oxygen. Hereby, the acid-producing bacteria creates anaerobic condition which is essential for the methane producing microorganisms. Also, they reduce the compounds with low molecular weights into alcohols, organic acids, amino acids, carbon dioxide, hydrogen sulphide and traces of methane. From a chemical point, this process is partially endergonic (i.e. only possible with energy input), since bacteria alone are not capable of sustaining that type of reaction. Below equations demonstrate how glucose is converted into acetic acid:



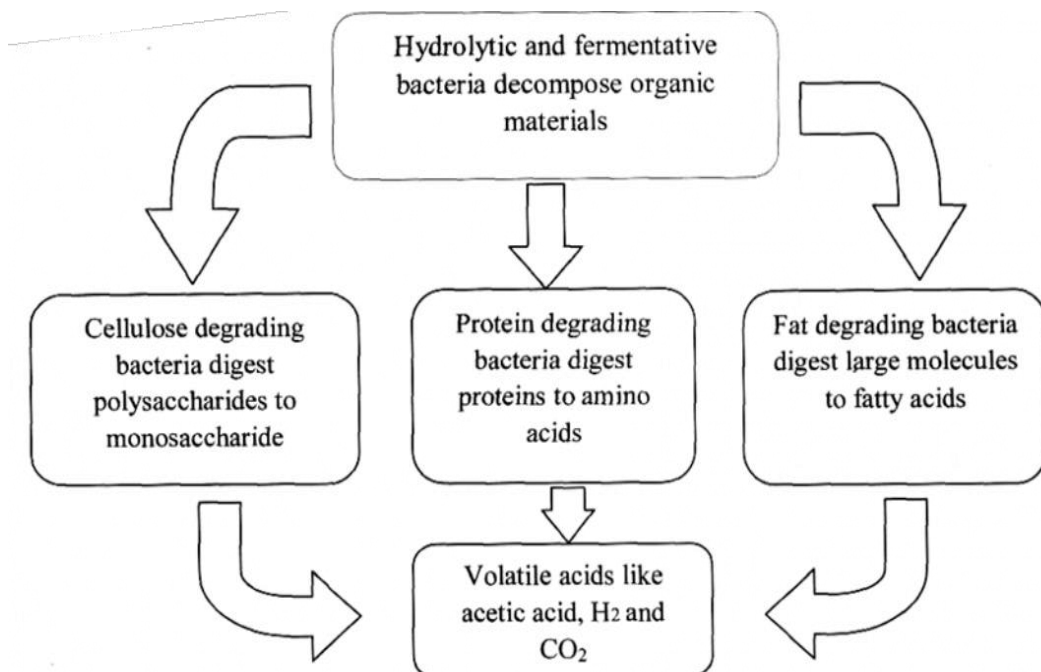
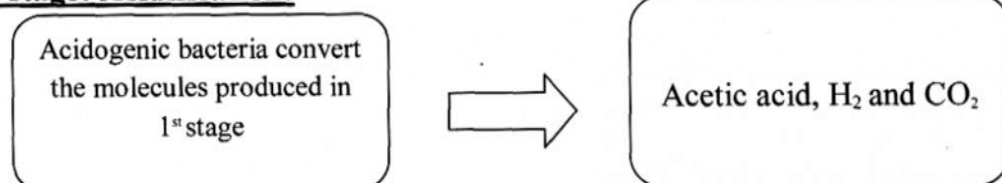
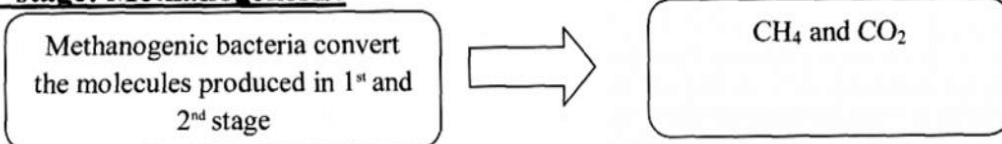
The above equation shows how glucose is converted into ethanol in the first

equation, then into propionate and third equation shows the formation of acetic acid.

METHANOGENES : (Methane formation) Methane-producing bacteria, which were involved in the third step, decompose compounds having low molecular weight. They utilize hydrogen, carbon dioxide and acetic acid to form methane and carbon dioxide. Under natural conditions, CH₄ producing microorganisms occur to the extent that anaerobic conditions are provided, e.g. under water (for example in marine sediments),and in marshes. They are basically anaerobic and very sensitive to environmental changes, if any occurs. The methanogenic bacteria belong to the archaeobacterial genus, i.e. to a group of bacteria with heterogeneous morphology and lot of common biochemical and molecular -biological properties that distinguished, them from other bacteria. The main difference lies in the makeup of the bacteria's cell walls. Chemical reactions during methanogenic can be summarized as describe below (4):



Symbiosis of bacteria: Methane and acid-producing bacteria act in a symbiotic way. Acid producing bacteria create an atmosphere with ideal parameters for methane producing bacteria (anaerobic conditions, compounds with a low molecular weight). On the other hand, methane-producing microorganisms use the intermediates of the acid producing bacteria. Without consuming them, toxic conditions for the acid-producing microorganisms would develop. In real time fermentation processes the metabolic actions of various bacteria acts in a design. No single bacteria is able to produce fermentation products alone as it requires others too. Biogas production process (Anaerobic digestion) is a multiple-stage process in which some main stages are:-

1st stage: Hydrolysis**2nd stage: Acidification:****3rd stage: Methanogenesis:****1.9 TYPES OF BIOGAS PLANTS:****1.9.1 FIXED-DOME PLANTS:**

A fixed-dome plant consists of a digester with a fixed, non-movable gas holder, which sits on top of the digester. When gas production starts, the slurry is displaced into the compensation tank. Gas pressure increases with the volume of gas stored and the height difference between the slurry level in the digester and the slurry level in the compensation tank.

The costs of a fixed-dome biogas plant are relatively low. It is simple as no moving parts exist. There are also no rusting steel parts and hence a long life of the plant (20 years or more) can be expected.[19]

The plant is constructed underground, protecting it from physical damage and saving space. While the underground digester is protected from low temperatures at night and during cold seasons, sunshine and warm seasons take longer to heat up the digester. No day/night fluctuations of temperature in the digester positively influence the bacteriological processes. The construction of fixed dome plants is labour-intensive, thus creating local employment. Fixed-dome plants are not easy to build. They should only be built where construction can be supervised by experienced biogas technicians. Otherwise plants may not be gas-tight (porosity and cracks).

The basic elements of a fixed dome plant are shown in the figure below:

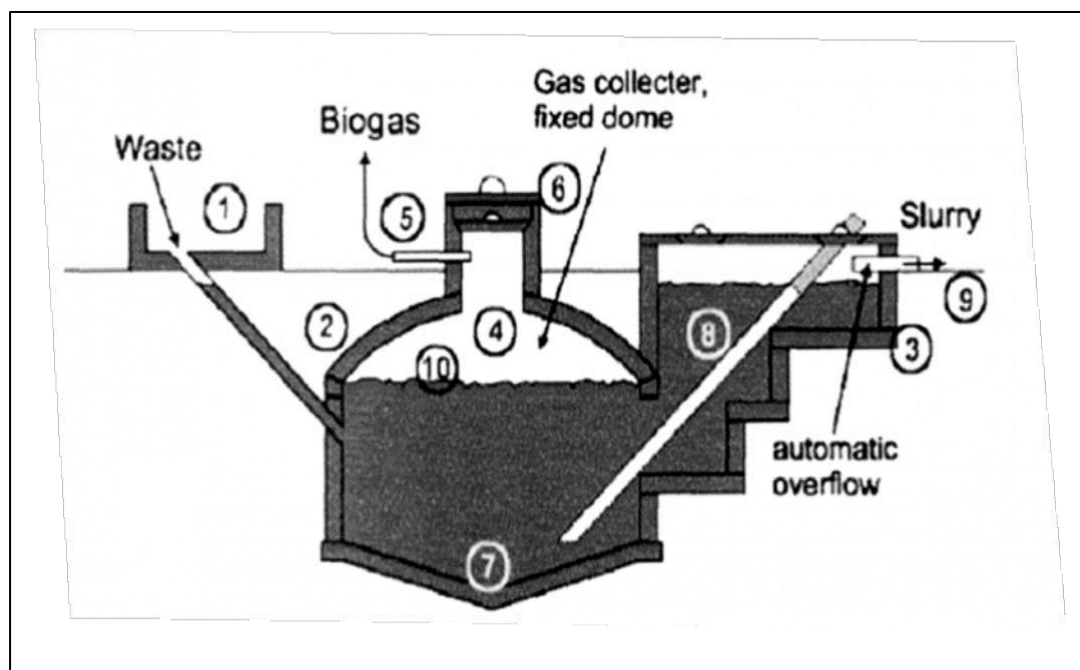


Figure 1.3 Fixed dome plant lay out (Source – Biogas production by Anuj Kumar Chandel)

1. Mixing tank with inlet pipe and sand trap.
2. Digester.
3. Compensation and removal tank.
4. Gas holder.
5. Gas pipe.
6. Entry hatch, with gaslight seal.
7. Accumulation of thick sludge.
8. Outlet pipe.
9. Reference level.
10. Supernatant scum, broken up by varying level.

Function- A fixed-dome plant comprises of a closed, dome-shaped digester with a immovable, rigid gas-holder and a displacement pit, also named ‘compensation tank’. The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the compensating tank. Gas pressure increases with the volume of gas stored i.e. with the height difference between the two slurry levels. If there is little gas in the gas holder, the gas pressure is low.

Digester- The digesters of fixed-dome plants are usually masonry structures, structures of cement and ferro-cement exist. Main parameters for the choice of material are:

- Technical suitability (stability, gas- and liquid tightness);
- Cost-effectiveness;
- Availability in the region and transport costs;
- Availability of local skills for working with the particular building material.

Fixed dome plants produce just as much gas as floating-drum plants, if they are gas-tight. However, utilization of the gas is less effective as the gas pressure fluctuates substantially. Burners and other simple appliances cannot be set in an optimal way. If the gas is required at constant pressure (e.g., for engines), a gas pressure regulator or a floating gas-holder is necessary.

Gas Holder - The top part of a fixed-dome plant (the gas space) must be gas-tight. Concrete, masonry and cement rendering are not gas-tight. The gas space must therefore be painted with a gas-tight layer (e.g. ‘Water-proofer’, Latex or synthetic paints). A possibility to reduce the risk of cracking of the gas-holder consists in the construction of a weak-ring in the masonry of the digester. This “ring” is a flexible joint between the lower (water-proof) and the upper (gas-proof) part of the hemispherical structure. It prevents cracks that develop due to the hydrostatic pressure in the lower parts to move into the upper parts of the gas-holder.

Types of Fixed Dome Plants:

- Chinese fixed-dome plant is the archetype of all fixed dome plants. Several million have been constructed in China. The digester consists of a cylinder with round bottom and top.
- Janata model was the first fixed-dome design in India, as a response to the Chinese fixed dome plant. It is not constructed anymore. The mode of construction led to cracks in the gasholder - very few of these plants had been gas-tight.
- Deen bandhu, the successor of the Janata plant in India, with improved design, was more crack-proof and consumed less building material than the Janata plant, with a hemisphere digester.

Climate and Size - Fixed-dome plants must be covered with earth up to the top of the gas filled space to counteract the internal pressure (up to 0.15 bar). The earth cover insulation and the option for internal heating make them suitable for colder

climates. Due to economic parameters, the recommended minimum size of a fixed-dome plant is 5 m³. Digester volumes up to 200 m³ are known and possible.[20]

Advantages:

- Low initial costs and long useful life-span;
- No moving or rusting parts involved;
- Basic design is compact, saves space and is well insulated;
- Construction creates local employment.
- If well constructed, fixed dome plants have a long life span.
- The underground construction saves space and protects the digester from temperature changes.

Disadvantages:

- Masonry gas-holders require special sealants and high technical skills for gas-tight construction ;
- Gas leaks occur quite frequently;
- Fluctuating gas pressure complicates gas utilization;
- Amount of gas produced is not immediately visible, plant operation not readily understandable;
- Fixed dome plants need exact planning of levels;
- Excavation can be difficult and expensive in bedrock.

Disadvantages are mainly the frequent problems with the gas-tightness of the brickwork gas holder (a small crack in the upper brickwork can cause heavy losses of biogas). Fixed-dome plants are, therefore, recommended only where construction can be supervised by experienced biogas technicians. The gas pressure fluctuates substantially depending on the volume of the stored gas. Even though the underground construction buffers temperature extremes, digester temperatures are generally low.

Variations: Some companies are now looking into small pre-fabricated fixed dome plants made of fibreglass which appears to be a low cost alternative to construction intensive masoned plants. A custom made plant can be produced in 2 days and -after transport- installed in less than a day.[21]

1.9.2 FLOATING DRUM PLANTS:

Floating-drum plants consist of an underground digester and a moving gas-holder. The gasholder floats either directly on the fermentation slurry or in a water jacket of its own. The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored. The gas drum is prevented from tilting by a guiding frame. If the drum floats in a water jacket, it cannot get stuck, even in substrate with high solid content.

Drum - In the past, floating-drum plants were mainly built in India. A floating-drum plant consists of a cylindrical or dome-shaped digester and a moving, floating gas-holder, or drum. The gas-holder floats either directly in the fermenting slurry or in a separate water jacket. The drum in which the biogas collects has an internal and/or external guide frame that provides stability and keeps the drum upright. If biogas is produced, the drum moves up, if gas is consumed, the gas-holder sinks back.

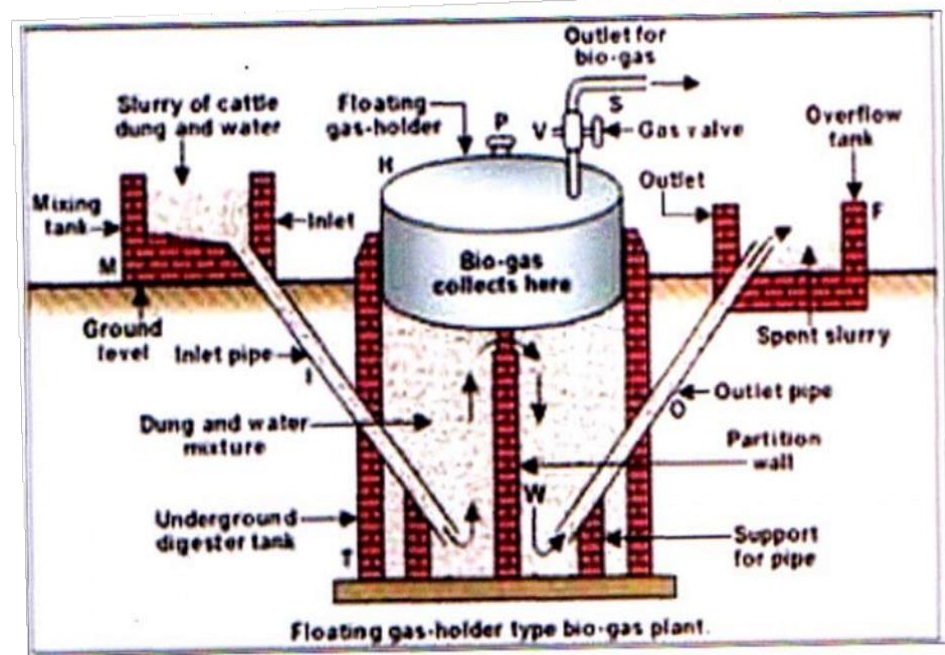


Figure 1.4 Floating doam plant lay out (Source– Biogas production by Anuj Kumar Chandel)

Size- Floating-drum plants are used chiefly for digesting animal and human faeces on a continuous feed mode of operation, i.e. with daily input. They are used most frequently by small-to middle-sized farms (digester size: 5-15 m³) or in institutions and larger agro industrial estates (digester size: 20-100 m³).

Material of Digester and Drum

The digester is usually made of brick, concrete or quarry-stone masonry with plaster. The gas drum normally consists of 2.5 mm steel sheets for the sides and 2 mm sheets for the top. It has welded-in braces which break up surface scum when the drum rotates. The drum must be protected against corrosion. Suitable coating products are oil paints, synthetic paints and bitumen paints. Correct priming is important. There must be at least two preliminary coats and one topcoat. Coatings of used oil are cheap. They must be renewed monthly. Plastic sheeting stuck to bitumen sealant has not given good results. In coastal regions, repainting is necessary at least once a year, and in dry uplands at least every other year. Gas production will be higher if the drum is painted black or red rather than blue or white, because the digester temperature is increased by solar radiation. Gas drums made of 2 cm wire mesh reinforced concrete or fibre-cement must receive a gas-tight internal coating. The gas drum should have a slightly sloping roof, otherwise rainwater will be trapped on it, leading to rust damage. An excessively steep-pitched roof is unnecessarily expensive and the gas in the tip cannot be used because when the drum is resting on the bottom, the gas is no longer under pressure.

Floating-drums made of glass- fibre reinforced plastic and high-density polyethylene

have been used successfully, but the construction costs are higher compared to using steel. Floating-drums made of wire-mesh-reinforced concrete are liable to hairline cracking and are intrinsically porous. They require a gas-tight, elastic internal coating. PVC drums are unsuitable because they are not resistant to UV.

Guide Frame

The side wall of the gas drum should be just as high as the wall above the support ledge. The floating drum must not touch the outer walls. It must not tilt, otherwise the coating will be damaged or it will get stuck. For this reason, a floating-drum always requires a guide. This guide frame must be designed in a way that allows the gas drum to be removed for repair. The drum can only be removed if air can flow into it, either by opening the gas outlet or by emptying the water jacket.

The floating gas drum can be replaced by a balloon above the digester. This reduces construction costs but in practice problems always arise with the attachment of the balloon to the digester and with the high susceptibility to physical damage.

Types of Floating Drum Plants:

- **KVIC model** with a cylindrical digester, the oldest and most widespread floating drum biogas plant from India.
- **Pragati model** with a hemisphere digester.
- **Ganesh model** made of angular steel and plastic foil.
- Floating-drum plant made of pre-fabricated reinforced concrete compound units
- Floating-drum plant made of fibre-glass reinforced polyester
- Low cost floating-drum plants made of plastic water containers or fibre glass drums:

ARTI Biogas plants

- **BORDA model:** The BORDA-plant combines the static advantages of hemispherical digester with the process-stability of the floating-drum and the longer life span of a water jacket plant.

Advantages:

- The construction is simple and operation is easily understandable.
- The volume of stored gas is directly visible.
- The gas pressure is constant, determined by the weight of the gas holder.
- The construction is relatively easy, construction mistakes do not lead to major problems in operation and gas yield.

Disadvantages:

- High material costs of the steel drum;
- The susceptibility of steel parts to corrosion, because of this, floating drum plants have a shorter Life span than fixed-dome plants;
- Regular maintenance costs for the painting of the drum.

1.10 SOME POPULAR INDIAN BIOGAS MODEL:

There are three popular Indian designs of biogas model namely: KV LC, Janata and Deen- bandhu biogas plants. A brief description of the three models is given below:

1.10.1 KVIC plant :

It was in or around the year 1945 that Scientists at Indian Agricultural Research Institution (IARI), New Delhi worked on semi-continuous flow digesters and in the year 1961 Kh and Village Industries Commission (KVIC) patented a design which is being popularised various agencies in many countries. This design consists of a deep well shaped underground : digester connected with inlet and outlet pipes at its bottom, which are separated by a partition wall dividing the 3/4th of the total height into two parts. A mild steel gas storage drum inverted over the slurry which goes up and down around a guide pipe with the accumulation and withdrawal of gas. Now FRP and ferro-cement gas holders are also being used in KV plant.[22]

1.10.2 Janata plant:

The Janata model is a fixed roof biogas plant which was developed by PRAD in 1978; this is also a semi-continuous flow plant. Main feature of Janata design is that the digester and gas holder are part of a composite unit made of bricks and cement masonry. It has a cylindrical digester with dome shaped roof and large inlet and outlet tanks on two sides. It required shuttering for making the dome shaped roof and skilled and trained master mason is a must for the construction of Janata biogas plant. This plant costs about 20-300/o less than the cost KVIC floating drum type plant.

1.10.3 Deen -bandhu plant:

As a result of concerted efforts to reduce the cost of biogas plants, AFPRO designed and developed a new low cost fixed roof biogas plant which has been named Deen-bandhu Biogas Plant (DBP). The reduction in cost of DBP has been brought about without adversely affecting the efficiency of biogas plants. After intensive trial and testing under controlled conditions and field applications, designs of DBP have been standardized for family size installations. The designs of Deen-bandhu biogas plants have been approved by the Department of Non-Conventional Energy Sources (ONES), Govt. of India for extension under the National Project on Biogas Development (NPBD).[23]

Deen-bandhu biogas plants are built with locally available building materials such as brick, cement and sand. Unlike Janata biogas plants, for constructing plants of this design no shuttering is required for making the dome shaped roof. This also results in less labour and time required for completing the construction. Details of constructional methodology and other aspects related to Deen-bandhu biogas plants can be obtained from "A Manual of Deen-bandhu Biogas Plants" prepared by AFPRO and published by Tata McGraw-Hill Publishing Co. Ltd, New Delhi.[24]

1.11 COMPARISON AMONG KVIC, JANATA AND DEEN-BANDHU MODEL :

Sl. No.	KVIC Model	Janata Model	Deen-bandhu Model
1.	The digester of this plant is a deep well shaped masonry structure. In plants of above 3 m ³ capacity a partition wall is provided in middle of the digester.	Digester of this plant is a shallow well shaped masonry structure. No partition wall is provided.	Digester is made of segments of two spheres one each for the top and bottom.
2.	Gas holder is generally made of mild steel. In is inverted into the digester and goes up and down with formation and utilization of gas.	Gas holder is an integral part of the masonry structure of the plant. Slurry from the gas storage portion is displaced out with the formation and comes back when it is used.	The structure described above includes digester and the gas storage chamber. Gas is stored in the same way as in the case of Janata Plants.
3.	The gas is available at a constant pressure of about 10 cm of water column.	Gas pressure varies from 0 to 90 cm of water column.	Gas pressure varies from 0 to 75 cm of water column.
4.	Inlet and outlet connections	Inlet and outlet tanks are large masonry structure the slurry displaced out of the digester with the formation of gas.	Inlet connection through A.C. Pipe Outlet tank is a large masonry to store slurry displaced out of the digester with the formation of gas
5.	Gas storage capacity of the plant is governed by the volume of gas holder.	It is the combined volume of inlet and outlet displacement chambers (portion of inlet and outlet tanks above the second step)	It is the volume of outlet displacement chamber
6.	The floating mild steel gas holder needs regular care and maintenance to prevent the gas holder from getting worn out because corrosion. It also have a short lifespan.	There is no moving part and hence no recurring expenditure. It is also has a long working life.	There is no moving part and hence no recurring expenditure. It also has a long working life.
7.	Installation cost is very high	It is cheaper than the KVIC type plants .	It is much cheaper than KVIC and Janata type plants.

1.12 INCINERATION AND ITS POTENTIAL

Incineration is a waste treatment process that involves the combustion of substances contained in waste materials. Industrial plants for waste incineration are commonly referred to as waste-to-energy facilities. Incineration and other high-temperature waste treatment systems are described as "thermal treatment". Incineration of waste materials converts the waste into ash, flue gas and heat. The ash is mostly formed by the inorganic constituents of the waste and may take the form of solid lumps or particulates carried by the flue gas. The flue gases must be cleaned of gaseous and particulate pollutants before they are dispersed into the atmosphere. In some cases, the heat that is generated by incineration can be used to generate electric power.[25]

Incineration with energy recovery is one of several waste-to-energy technologies such as gasification, pyrolysis and anaerobic digestion. While incineration and gasification technologies are similar in principle, the energy produced from incineration is high-temperature heat whereas combustible gas is often the main energy product from gasification. Incineration and gasification may also be implemented without energy and materials recovery.

In several countries, there are still concerns from experts and local communities about the environmental effect of incinerators .

In some countries, incinerators built just a few decades ago often did not include a materials separation to remove hazardous, bulky or recyclable materials before combustion. These facilities tended to risk the health of the plant workers and the local environment due to inadequate levels of gas cleaning and combustion process control. Most of these facilities did not generate electricity.[26]

Incinerators reduce the solid mass of the original waste by 80–85% and the volume (already compressed somewhat in garbage trucks) by 95–96%, depending on composition and degree of recovery of materials such as metals from the ash for recycling.^[2] This means that while incineration does not completely replace landfilling, it significantly reduces the necessary volume for disposal. Garbage trucks often reduce the volume of waste in a built-in compressor before delivery to the incinerator. Alternatively, at landfills, the volume of the uncompressed garbage can be reduced by approximately 70% by using a stationary steel compressor, albeit with a significant energy cost. In many countries, simpler waste compaction is a common practice for compaction at landfills.

Incineration has particularly strong benefits for the treatment of certain waste types in niche areas such as clinical wastes and certain hazardous wastes where pathogens and toxins can be destroyed by high temperatures. Examples include chemical multi-product plants with diverse toxic or very toxic wastewater streams, which cannot be routed to a conventional wastewater treatment plant.[27]

Waste combustion is particularly popular in countries such as Japan, Singapore and the Netherlands, where land is a scarce resource. Denmark and Sweden have been leaders by using the energy generated from incineration for more than a century, in localised combined heat and power facilities supporting district heating schemes. In 2005, waste incineration produced 4.8% of the electricity consumption and 13.7% of the total domestic heat consumption in Denmark. A number of other European countries rely

heavily on incineration for handling municipal waste, in particular Luxembourg, the Netherlands, Germany, and France.

An incinerator is a furnace for burning waste. Modern incinerators include pollution mitigation equipment such as flue gas cleaning. There are various types of incinerator plant design: moving grate, fixed grate, rotary-kiln, and fluidised bed. [28]

1.12.1 Burn pile

The burn pile or the burn pit is one of the simplest and earliest forms of waste disposal, essentially consisting of a mound of combustible materials piled on the open ground and set on fire, leading to pollution.

Burn piles can and have spread uncontrolled fires, for example, if the wind blows burning material off the pile into surrounding combustible grasses or onto buildings. As interior structures of the pile are consumed, the pile can shift and collapse, spreading the burn area. Even in a situation of no wind, small lightweight ignited embers can lift off the pile via convection, and waft through the air into grasses or onto buildings, igniting them. Burn piles often do not result in full combustion of waste and therefore produce particulate pollution.



Figure 1.5 - Burn pile incineration (Image Source – Incineration system handbook by Calvin R. Brunner)

1.12.2 Burn barrel

The burn barrel is a somewhat more controlled form of private waste incineration, containing the burning material inside a metal barrel, with a metal grating over the exhaust. The barrel prevents the spread of burning material in windy conditions, and as the combustibles are reduced they can only settle down into the barrel. The exhaust grating helps to prevent the spread of burning embers. Typically steel 55-US-gallon (210 L) drums are used as burn barrels, with air vent holes cut or drilled around the base for air intake. Over time, the very high heat of incineration causes the metal to oxidize and rust, and eventually the barrel itself is consumed by the heat and must be replaced.

The private burning of dry cellulosic/paper products is generally clean-burning, producing no visible smoke, but plastics in the household waste can cause private burning to create a public nuisance, generating acrid odors and fumes that make eyes burn and water. A two-layered design enables secondary combustion, reducing smoke. Most urban communities ban burn barrels and certain rural communities may have prohibitions on open burning, especially those home to many residents not familiar with this common rural practice. [29]

1.12.3 Moving Grate Incinerator

The main benefits of the moving grate are its well-proven technology, ability to accept wide variations in waste composition and heat values, and ability to be produced in extremely large units. The primary drawback is the expense, which is relatively significant for investment and maintenance.[30] The waste is burned in layers on the grate that moves the waste through the furnace in a traditional mass-burning incinerator based on a moving grate. On the grate, the waste is dried before being burned at a high temperature with an air supply.

The non-combustible waste fractions, which include the ash, exit the grate through the ash chute as slag (bottom ash). The bottom ash (slag), which drops into the water trap of the slag pusher from the grate's end, is then cooled by coming in contact with cooling water before moving on to the conveyor system. Typically, 10 to 25 percent of the weight of the waste feed is made up of slag.

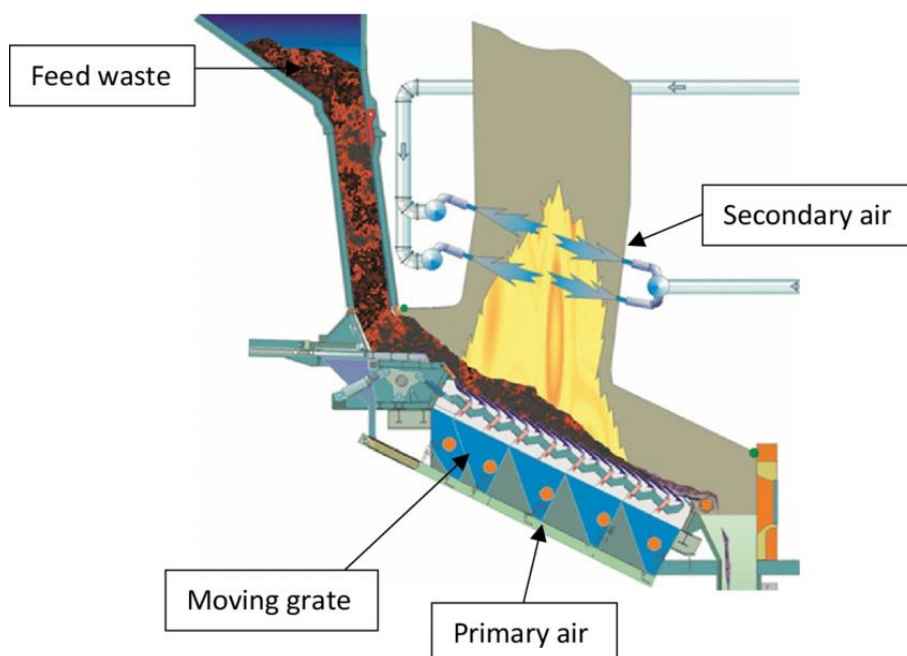


Figure1.6: Moving grate incinerator

(Image Source – Incineration system handbook by Calvin R. Brunner)

1.12.4 Fixed grate Incinerator

The older and simpler kind of incinerator was a brick-lined cell with a fixed metal grate over a lower ash pit, with one opening in the top or side for loading and another opening in the side for removing incombustible solids called clinkers. Many small incinerators formerly found in apartment houses have now been replaced by waste compactors.

1.12.5 Rotary Kiln Incinerator

The basic design consists of two thermal treatment chambers: a primary chamber that is slightly slanted and into which waste is fed (along with hot exhaust air containing oxygen), rotated, and thermally decomposed by heat radiation from the secondary chamber; and a re-combustion chamber that is located at the back of the kiln and into which the decomposition air and the remaining waste is completely burned with the supply of secondary air. It is built with a rotating combustion chamber that keeps the garbage circulating continually. The waste can vaporize, which makes burning easier. By modifying the inclination angle and rotational rate of the kiln, the waste throughput rate can be managed. Solids burnout rates and particulate entrapment in the flue gas are higher for rotary kiln incinerators than for other incinerator designs due to the waste's turbulent motion in the primary chambers. Because of this, gas cleaning accessories are frequently added to rotary kiln incinerators.

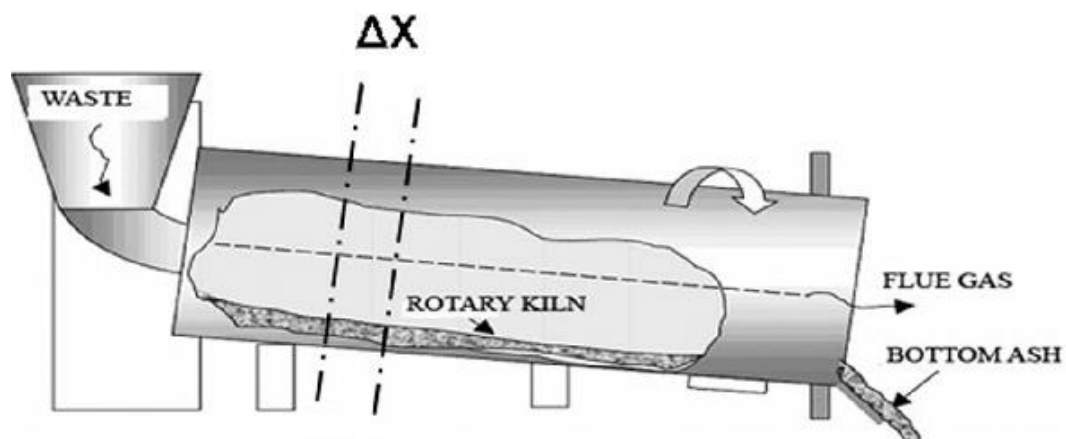


Figure 1.7 : Rotary kiln combustion chamber

(Image Source – Incineration system handbook by Calvin R. Brunner)

The advantages of rotary kilns include less NO_x production and heat elimination of dangerous compounds.

In a rotary kiln incinerator, typical waste types that can be treated include Pharmaceutical waste, Hazardous waste, and Medical waste, such as sharps, infectious waste, surgical trash, clinical waste, laboratory waste, etc.

1.12.6 Fluidized Bed Incinerator

The process by which a fluid is passed through granular material in a solid state to change it into a fluid-like state is known as the principle of fluidization. The reactor typically comprises a vertical steel vessel lined with refractory material and a bed of granular material, such as limestone, silica sand, or ceramic material.

Air is injected into the bed through several nozzles at the bottom of the incinerator to keep it fluid. This results in a violent agitation of the bed material where the burning of trash takes place in close contact with the bed material and combustion air. Because of the comparatively low extra air level made possible by this, a high thermal efficiency of up to 90% is possible.

These are employed in the incineration of sewage sludge and industrial waste and are primarily used for homogenous waste types, including liquid waste.[31]

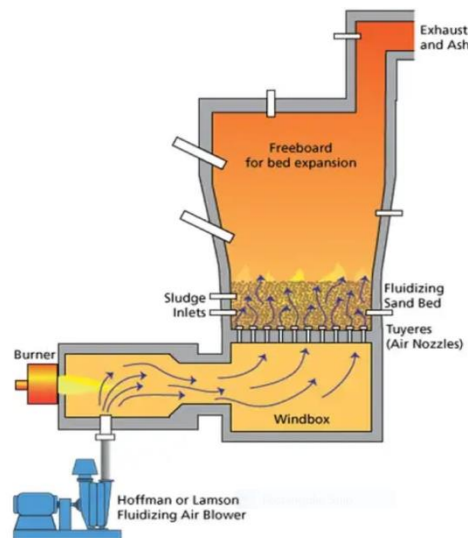


Figure 1.8 : Fluidised bed incinerator

(Image Source – Incineration system handbook by Calvin R. Brunner)

2 . OBJECTIVE & SCOPE OF THIS STUDY

2.1 OBJECTIVES OF THIS STUDY :

1. To harvest energy from municipal solid waste
2. To study the Calorific Value and Moisture Content of Different Solid Waste source
3. Comparison of Calorific Value of different sample of Solid Waste Source
4. Estimation of Mean Calorific Value of the Solid Waste Source
5. To study about the Heat & Electrical Energy generation possibility from the Solid Waste

2.2 SCOPE OF THIS STUDY :

1. Collection of MSW from South Dum Dum Municipality & Pramod Nagar Dumping Yard .
2. Analysis of physical and chemical parameters using standard prescribed method of MSW, collected from South Dum Dum Municipality and Pramod Nagar Dumping Yard .
3. To estimate the energy generation possibility and to establish all design parameters at field scale model for validation of incineration plant.

3. LITERATURE REVIEW

3. LITERATURE REVIEW

There are many studies carried out for waste to energy generation through incineration . Some case studies are given below to overview an idea about incineration process .

3.1 NATIONAL STATUS :

R. Dubey et al. (2015) examined enormous potential of solid waste to energy potential in India. Various components of municipal solid waste (MSW) have an economic value and can be recovered, reused or recycled cost effectively. Currently, the informal sector picks up part of the resources from the streets and bins to earn their living. However, a sizeable portion of organic waste as well as recyclable material goes to landfills untreated. Over 81% of MSW annually is disposed at open dump sites without any treatment. With planned efforts to Reduce, Reuse, Recover, Recycle and Remanufacture (5Rs) and appropriate choice of technology, the country can profitably utilize about 65% of the waste in producing energy and/or compost and another 10 to 15% to promote recycling industry and bring down the quantity of wastes going to landfills/ dumps under 20% (Planning Commission report 2014). Technology choices can be incineration, pyrolysis and biomethanation. The selection of waste to energy technologies therefore offers different approach of managing waste.

M. Singh et. al. (2016) verified that the energy generation for the 10 years (2015–2025) from municipal solid waste (MSW) in Faridabad, Haryana, India. Forecasting of MSW was analyzed based on three collection efficiencies (50%, 70%, and 80%) in Faridabad. The result shows that 2.65 kg of MSW is required to generate one unit of electrical energy with thermal conversion system. It was also obtained that approximate 2% of required electrical energy would be obtained from waste-to-energy (WTE) system in Faridabad over a period of 10 years (2015–2025). The result presented here could be a decision matrix for municipalities to develop effective waste management system for upcoming smart cities in India. Moreover, another novelty of this study reflects that cities having similar waste characteristics and population index could adopt this study for waste management and energy recovery. Proposed WTE system would reduce volume of the solid waste thereby improve environment of the city.

Sudhir Kumar et. al. (2017) attempted to estimate the quantity solid waste that can be generated in the ELURU city, A.P, INDIA per day and to estimate the generation potentiality of energy through combustion of solid waste. The waste to energy industry has proven itself to be an environmentally friendly solution to the disposal of municipal solid waste and the production of energy. Waste to -energy is now a clean, renewable, sustainable source of energy. The estimation of energy content of municipal solid waste in Eluru Municipal Corporation is discussed in this paper. The data related to number of house holds in division wise is collected from Municipal corporation of Eluru as 39,996. Out of the 50 divisions in Eluru Municipal Corporation based on income six divisions are selected for random survey covering Low, Medium and high income groups. Division maps are collected from the corporation for the sample survey divisions. The divisions selected for Sampling survey are re mapped representing minimum of 10% houses selected in each division

covering the total geographical location. House hold collection of solid waste is done physically in all the six divisions selected for estimating the per capita waste generation in the city. By physical weighment of all the waste collecting vehicles the total waste collected in the city is estimated and the same is compared by using the calculated per capita waste generation taking the total population of the city in to consideration to find out the quantity of waste generated in the corporation. Then a representative sample of the corporation using quartering method is collected from the dump yard. The representative sample of the city is sent for lab analysis at a MOEF recognized lab to estimate the calorific value and the same is compared by conducting several trials at the experimental setup designed with conventional approach on a Bomb calorimeter. It is estimated that by combusting the solid waste in ELURU Municipal Corporation it is possible to generate nearly 3MW of power.

M.K. Shukla et. al. (2019) Stated that the Ministry of New and Renewable Energy (MNRE), exists a capacity of approximately 1,700 MW from city waste (1,500 from MSW and 225 MW from sewage) and approximately 1,300 MW from commercial waste. The ministry is also actively selling the technology of electricity from waste, via providing subsidies and incentives for the projects. Indian Renewable Energy Development Agency (IREDA) estimates suggest that India has, to this point, realized the handiest about 2% of its waste-to-strength ability. A marketplace analysis predicts that the Indian municipal stable waste to the strength market should be developing at a compound annual growth fee of 9.7% .

N. K. Patel et. al. (2021) pointed out that landfill gas emissions from conventional solid waste collection in developing countries are effectevly contributing to global climate change (Tan et al., 2018). Traditional land filling is less and less attention for the cities due to its disadvantages of less efficient energy recovery and more greenhouse gas emission in comparison to the popular incineration means to treat the MSW (Han, Long, Li, & Qian, 2019). From another energy saving methods, the need of the waste-to-energy technologies is expected to increase five times in less than 10 years (Pike_Research, 2018). On the other hand, waste incineration can minimize its mass by up to 90%, hence effectively decreases the need of landfills and final disposal. It can also be utilised on to provide more cost-effective waste management regimes by reducing the number of the trips over long distances after the incineration and optimization the MSW collection strategy from the waste generation points to the incineration plants.

Pavitra L et. al. (2020) analysed that Waste Incinerators can decrease the quantity of waste by 95% and reduce the solid quantity of the original waste by 80-85% depending on the components that were in solid waste .Therefore incineration reduces dependency on land fills. Efficient Waste Management Incineration plays a vital role in making waste management easier and more efficient. Incineration can burn up to 90% of the total waste generated and sometimes even more. However, landfills only allow organic decomposition without making much difference, and non-organic waste keeps accumulating. Production of Heat and Power Incineration plants generate energy from waste that can be used to generate electricity or heat. During the 2000 s, energy costs increased considerably. So a lot of countries incorporated the heat and energy produced from waste incinerators for the generation of power by using steam turbines. It can be

used to power the needs of people living nearby. Reduction of Pollution Research has shown that solid waste incinerators are less likely to pollute the environment than landfills. One particular study done during 2014 lawsuit in the US showed that a waste incinerator location was more environmental friendly compared to a landfill. Saves on Transportation of Waste Incineration plants can be near cities or towns. This is advantageous since it means waste does not have to be driven for long distances for dumping. It significantly reduces the cost of transport; the money can then be spent on the wellbeing of the community and sustaining the growth of a city or district. Additionally, it reduces the harmful gases released by vehicles during transportation, thus drastically reduce the overall carbon footprint. 6. Provides Better Control Over Odour and Noise Incineration plants can provide less bad smells because waste gets burnt, unlike landfills, where waste is allowed to decay, thereby emitting unpleasant smells, which causes air pollution. The production of methane in landfills may also lead to explosions that causes noise pollution.

S Rathi et.al (2021)used Dulong Formulae heat energy in incineration technology to calculate and analyse potential generation of electricity in Kanpur city of 33MW from MSW of 1200 tonnes/day by considering conversion efficiency, station allowance, unaccounted heat loss and net power generated and classified solid wastes on physical and chemical composition. They explained new technology of circulating fluidized bed and emission of reduction by using equipment such as house filtration, flue gas cleaning and activated carbon in incinerator, adopted by 30 plants for development . Biodegradable matter shares 31-36% of total MSW in big cities and 65% in small cities having calorific value of around 5000KJ/Kg. Dioxin emission was limited to 1.0ng TEQ/Nm³ . It was explained that classified and compared cities on the basis of population, MSW composition, total waste generated; very big city, big city, medium city, small city and calculated potential of 1700 MW electricity from WTE incineration with some solutions and suggestion to problems occurring in MSWM. It was proposed the opinion to solve waste problem as using it as a resource. It was explained that WTE technology was successful and reliable because of thermal conversion, heat recovery and air pollution technique to reduce health and environmental risk, landfill substitute .

3.2 INTERNATIONAL STATUS

A.I. Obanor et. al. (2014) stated that Waste-to-energy (WTE) technology in Nigeria is still at the infancy stage whereas in Sweden the technology is now so advanced that energy in the form of heat and electricity has commercially been recovered from waste. They examined waste-toenergy development and its success factors in Sweden with a view to instigating the deployment of a modified Sweden's waste-to-energy model in Nigeria to enhance her WTE capacity. The study was carried out in two phases. The first phase involved field visits to some waste-to-energy plants in Sweden and the second phase was a desk research of available data on current WTE development in Nigeria, Sweden's energy sector as well as factors responsible for its successful WTE development. The result from the study showed that Sweden generated about 2.0TWh of electricity from about 5.7 million tonnes of waste in its WTE plants in 2014. The success of WTE development and growth in Sweden is hugely as a result of the support from the Swedish government via enacting enabling policies and adequate funding. With about 14 million tonnes of combustible waste available in Nigeria, about 4.4TWh of electricity

could be generated annually if WTE development in the country receives similar support from the Nigerian government.

Zi Jun Yong et. Al. studied the development of Incinerator plant in Malaysia .In June 2011, XCN Technology Sdn Bhd constructed an incineration plant located on a 0.8 ha land area at Teluk Cempedak, Pangkor Island. The plant can reduce incoming waste volume up to 94% using the Autogenous Combustion Technology (ACT). In January 2012, the plant commenced operation and was handed over to MHLG. The plant is capable of combusting up to 20 tonnes of MSW per day. Two more mini incinerators located at Tioman Island's facility is capable of incinerating 3221 tons of MSW per year. Two other mini incinerators each were constructed in Cameron Highland and Labuan, where each incinerator has a capacity of combusting 15 and 60 tonnes of MSW per day respectively. None of the four-mentioned incinerator could utilize the MSW to produce energy and generate electricity rather than only to minimize the volume of the incoming MSW. The Langkawi incineration plant is the most comprehensive plant and was the first waste incineration plant in Malaysia to utilize the concept of WTE technology. The Langkawi plant was constructed at a cost of RM68 million and the plant is estimated to process 100 tons per-day of waste to generate one megawatt of electricity. There were two units of mini incinerator installed where the model of the incinerator is Hoval GG42. The operation of the two mini incinerators was monitored by the local authority of Langkawi Town Council. So far, the incinerator plant in Langkawi is the only incinerator plant in Malaysia to practice solid waste segregation at the site before the waste stream was fed into the incinerator. Waste which is not suitable for the incineration process due to high moisture content such as food waste and other wet waste was later dumped into a nearby landfill. The efficiency of the of Langkawi's plant is estimated to be around 80%–90% . The incinerator disposes approximately 100 tons of waste per day and runs on power generated from the WTE technology. The waste heat generated from the incineration process is converted to 1 MW of electricity. The main features of the plant included waste separation systems, rotary kilns, waste heat recovery boilers, air pollution control systems, and a fully condensing steam turbine generator. The Kajang WTE plant, which consists of a refuse-derived fuel (RDF) facility, is the most comprehensive incinerator as the system incorporates the refused-derived-facility (RFD) operation in Malaysia. WTE or refuse-derived-fuel technologies are both energy recovery initiatives currently emerging at Malaysia and are given priority in solid waste management. In 2008, the Kajang WTE facility was commissioned and has the capacity to process approximately 1100 tons of MSW daily into RDF which is used to produce approximately 8 MW of electricity daily. A total of 3 MW of electricity produced from the RDF plant is used to power the plant and the remainder 5 MW is fed and sold into the national electricity grid via the Feed-in-Tariff (FiT) mechanism . At present, there is a plan to increase the export capacity of electricity generation from 5 to 6 MW. In addition, the current RFD technology only allows 77% of the energy stored within the MSW to be recovered in the form of fuel. It is anticipated that the energy recovered from MSW is targeted to increase to 83% by mixing biogas produce from organic waste via AD into the process, hence making the overall operation more efficient . The increase in MSW generation from 6.37 to 13.38 Mt from year 2010 to 2030 greatly increases the potential of MSW application of WTE. The calorific value of the MSW at Malaysia is estimated between 1500 to 2600 kcal/kg, with energy potential from the incineration plant operating based on the provided calorific value incinerator plant at Malaysia which

will have the potential to generate 640 kW/per day. Their study stated that there will be an increase of 60% in electrical generation from 2010 to 2030 by incineration plants as it is estimated that the increasing MSW as renewable source of energy in Malaysia has the potential to produce 5000 Gwh/year by 2020 and further increase to 6200 Gwh/y by year 2030.

Wen Chao Ma et. al. (2019) studied evolution of energy and metals recovery from urban wastes in the European Union and China during 2000 – 2018 . As a result of the zero-landfilling directive, in twenty years the European Union tripled its recycling rate (11%–30%) and its composting rate (6%–17%), doubled its WTE rate (14%–28%) and more than halved its landfilling (64%–25%). At the beginning of this century, the rapidly growing cities of China were literally surrounded by landfills. Therefore, the national government instituted policies, such as a credit of US\$30 per MWh of WTE (waste to energy) electricity that resulted in the construction, by 2020, of 510 WTE plants with an annual WTE capacity of 193 million tons. In comparison, the European Union (EU) WTE capacity is 96 million tons and the USA has remained static at about 27 million tons, i.e., 10% of its post-recycling MSW (municipal solid waste), with the other 90% being landfilled. In the first decade of this century, two WTE technologies, moving grate and circulating fluid bed were developed in China at about the same rate. However, since 2010, the moving grate technology has become dominant and the WTE plants are built functionally and esthetically comparable to and U.S. plants.

Nicolas J et. al (2020) deeply verified the power generation progress in Greece from MSW through incineration technology . Implementation of this scenario reduced the GHG emissions of the Power Generation Sector in Greece and reduced the nation's dependence on imported fossil fuels, thus supporting the efforts for economic growth of Greece. These additional benefits to the ones already mentioned prove that the use of MSW and RDF/SRF for energy production provided significant benefits not only to the environment but also to the economy and Power Generation Sector in Greece. The potential benefits are huge: Over 1.5 billion kWh/y, almost 2.5% of the total electricity production of Greece in 2020 , generated, and over 128000 t of lignite was saved annually. In addition, the CO₂ emissions can be highly reduced, over 3000 kt CO₂/y . The steam used for electricity production from the steam generators in power stations presents low enthalpy for extended heating systems, if it comes from a dedicated electricity production plant . But even then, the existing low enthalpy in the steam can be utilised for small scale domestic / residential type heating . A fast approximation of the quantities of thermal energy that can be utilised, based on the plant sizes proposed by Psomopoulos and Themelis in , and considering the data from typical power plants using fossil fuels for steam generators . Considering the existing conditions in Greece, even though the residential heating oil demand was reduced in recent years, the need for heat in residual sector and sanitary hot water remains at the same levels. Following the results presented there is a potential for 35000MWhth/y. Based on the fact that this energy is coming from low enthalpy steam, the utilisation is limited. Thus, it could be used only for small-scale district heating applications and production of sanitary hot water, or heating of water in swimming pools, replacing common diesel oil used in such applications. Considering that 1 MWh equals 0.086 toe or 103.2 L of oil equivalent, then, this energy could be equal to 3010 toe or 3612000 L, thus mainly reducing the oil consumption on the residential sector .

J. El Silveria et.al (2017) verified the annual rate of municipal solid waste production in Iran which increases and the per capita waste generation in Iran will be 0.6 kg/person.day. The process of conversion of waste-to-energy by Incineration in Iran is investigated and the future situation is estimated. Also, the trend of waste management methods and energy production are evaluated. At the end, the benefits of the waste-to-energy process at the capital of Iran (Tehran) are observed. Waste-to-Energy (WTE) facilities in waste management are used within 3 regions of 22 metropolitan areas of Tehran and serve 950,000 citizens. With manufacturing new WTE plants in Iran, it would be possible to prevent the burning of about 15 million barrels of oil or 255×10^7 cubic meters of natural gas annually and use these fossil fuels to produce petrochemicals and export them. The associated overall expenses of WTE is also estimated in different countries at a rate of GDP between 300 and 3,000 \$ per ton of MSW. By substituting WTE plants instead of oil basic plants, can reduce about 0.13 kg/kWh CO₂ emissions. While most of the power plants are gas basic, that will have an increase of CO₂ emissions of about 0.19 kg / kWh.

Sue Hiro Otoma et. al. (2019) verified the heat generation in Japan from waste incineration to generate electricity requires the addition of generating equipment, while the manufacture, construction, and operation of this equipment also uses energy. And owing to the problem of superheater tube corrosion caused by the hydrogen chloride and other substances formed in conjunction with waste combustion, municipal solid waste (MSW) power generation cannot raise steam temperature very much, and generating efficiency is said to be low, at between 10 and 15%. However, we have found that, in terms of life cycle energy balance, MSW generation is about the same as currently operating commercial power plants. We also examined life cycle energy balance in relation to repowering, which is meant to increase MSW generating efficiency, and reburning, which is aimed at limiting both NO_x and dioxin emissions. It was found that these were effective methods for energy recovery, and the gas turbines combined with waste incinerators for repowering have an optimum size that will improve overall efficiency.

Harpa Birgis Dottir (2020) mentioned in their study that in Denmark large amounts of residue materials from incineration plant are used in the road sector. The use of virgin materials predominates, but recycled materials are used increasingly. Construction of new roads often implies considerable interference with the environment, both related to the alignment of the road and the procurement of the large amounts of natural aggregates needed for the construction. Residues from waste incineration, especially bottom ash, can be utilized in road construction. In Denmark, approximately 80% of the 640 000 tons of bottom ash generated annually are utilized for construction purposes. The use of residues promotes the goals of minimizing the use of natural resources. However, many residues have a chemical composition that differs considerably from that of conventional materials, and when in contact with water constituents might leach from the materials into the environmental compartments. Introduction of residues into the road area therefore calls for augmented awareness of the environmental impacts. Laboratory leaching tests and field tests have been used to both estimate leaching from residues and for comparison with conventional materials. Assessment methods, such as risk

assessment and life cycle assessment, assessing the overall environmental impacts related to the residues have been suggested as a means of evaluating the consequences of recycling in broader perspective.

J. Sun et. al. (2020) mentioned in their study that in England the carbonation of MSWI residues after incineration represents a potential solution to sustainable waste management, the problem of decreasing landfill space, rising CO₂ emission levels and the depletion of natural aggregate resources. To apply this technology into industry, an interesting idea is to use flue gas as the source of CO₂. Indeed, Arickx *et. al.* studied the accelerated carbonation of BA utilising flue gas. At present, most research on carbonation of MSWI residues is focused on its influence on pH values and heavy metal leaching properties. Despite earlier work carried out under different reaction conditions to study the influence of these parameters, the reaction mechanisms and kinetics of accelerated carbonation are still not fully understood. The possibility of using flue-gas CO₂ to carbonate APC residues is evaluated. The influences of the fundamental parameters affecting the carbonation process .

Donald L Ziegler et. al. (2020) developed a fluidized-bed incineration system in Texas , USA which is being designed for combustion of transuranic waste. The facility is being designed for a capacity of about 82 kg/hr (180 lbs/hr), which will correspond to a heat release rate of about 1,600,000 kJ/hr (-1,500,000 Btu/hr). The process equipment design is based on data generated in the pilot plant and represents a scale factor of nine based on solid-waste feed rates. Approximately 45 percent of the heat of combustion will be extracted through the walls of the afterburner by a water-spray cooling system. In the pilot unit, most of the heat is removed as sensible heat of the combustion products. A water cooled heat exchanger in the flue gas stream will be used to remove approximately 55 percent of the heat of combustion from the process. In the pilot unit, the flue gas was cooled by dilution with room air. An air jet ejector was used in the pilot unit; high speed blowers will be used in the larger unit to provide motive force for gas flow through the process. An air classification system is being designed into the incinerator facility for removal of tramp metal from the combustible waste. The hand-sorted waste will be shredded and fed to the air classifier, which will remove the tramp metal. The combustibles will pass through a second stage of shredding prior to introduction to the primary reactor. Pilot scale tests have shown hand sorting only about 75 percent effective in removing tramp metal. A hand-held metal detector such as that used for personnel search at airports has been tested and determined to be of little aid to hand sorting. If tramp metal is not removed, it can cause damage to the shredding and feeding equipment. In addition, accumulation of tramp metal in the reactor will have a deleterious effect on fluidization. Product from the fluidized bed incinerator was used to evaluate palletisation for converting dust into a bulk mass form. The process resulted in a product density of about 2,000 kg/m³ , which represents a volume reduction factor of about two compared to the bulk ash volume. Some components of the mixture are water soluble, however, making a more permanent method of ash immobilization necessary.

4 . MATERIALS & METHODOLOGY

4.1 METHODOLOGY :

Methodology used in this study is described in the following flowchart :

1. **SAMPLE COLLECTION PRIMARY SOURCE : MUNICIPALITY**
COMPACTOR MACHINE (SOUTH DUM DUM)
2. **SAMPLE COLLECTION FINAL SOURCE : PRAMOD NAGAR DUMPING**
STATION (DUM DUM)
3. **PHYSICAL PROPERTY VERIFICATION OF SOLID WASTE**
(PERCENTAGE WISE SEGREGATION INTO GARBAGE/ASH/PAPER
PLASTIC / RUBBER ETC. IN LABORATORY)
4. **DETERMINATION OF CHEMICAL PARAMETERS OF MUNICIPAL**
SOLID WASTE : (A) - MOISTURE CONTENT (DRY MASS METHOD)

(B) - ORGANIC CARBON DETERMINATION (WALKLEY AND BLACK ,
1934)

(C) – DETERMINATION OF CALORIFIC VALUE (BY BOMB
CALORIMETER)

4.2 Description of Study Area

South Dum Dum is a city and a municipality of North 24 Parganas district in the Indian state of West Bengal. It is a part of the area covered by Kolkata Metropolitan Development Authority (KMDA) and a vital locality in Kolkata Metropolitan Area. It is a city on the northern part of Kolkata with a municipality called South Dum Dum municipality having 35 wards and 13.54 km² area. It is well connected to the developed part of the city through railways and roads. It is very near to Kolkata Airport, Shyambazar (epicenter of North Kolkata), Newtown (the IT hub of Kolkata), Esplanade (the employment hub of Kolkata and central business district). It is well connected to Alipore, Ballygunge and Jadavpur by suburban railways .

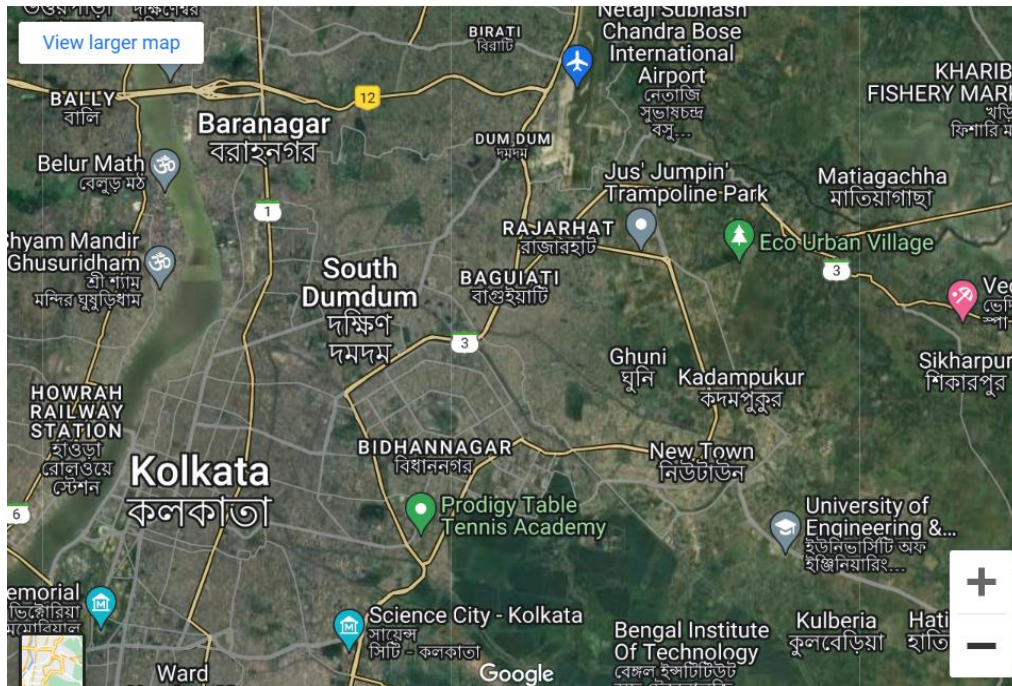


Figure 4.1 Location of south dum dum (Source - google earth)

South Dum Dum Municipality was established in 1870. South Dum Dum is located at $22.61^{\circ}\text{N } 88.40^{\circ}\text{E}$.

South Dum Dum is bounded by North Dum Dum (Municipality) and Dum Dum (Municipality) on the north, Baguiati and adjacent areas of VIP Road on the east, Salt Lake on the south and Baranagar is on the west .

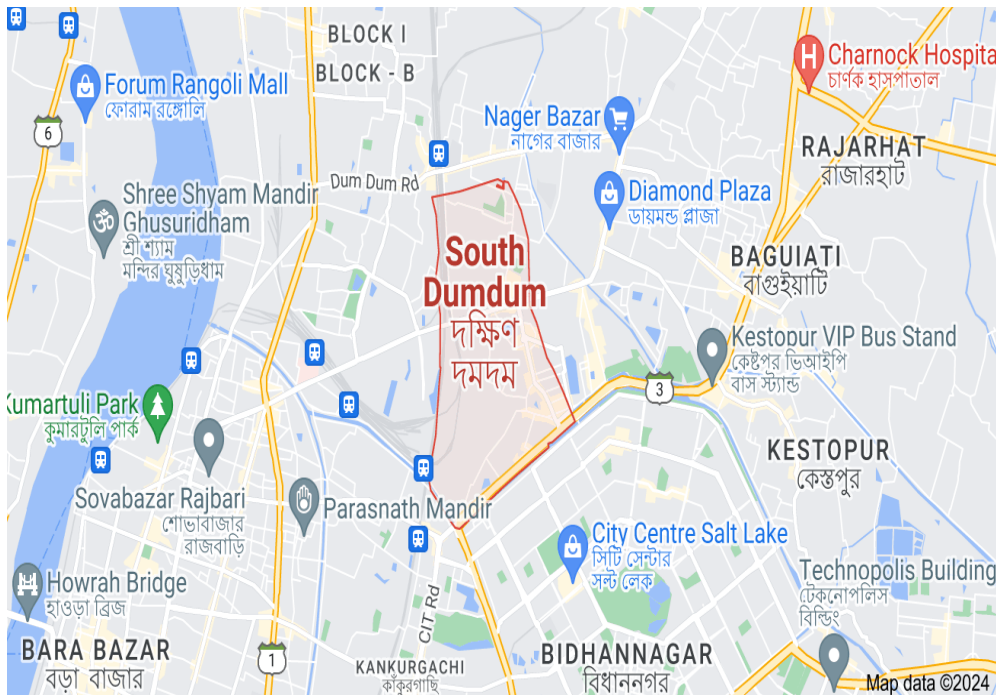


Table – 4.1 Population data of South dum dum
(Source – south dum dum municipality records)

Population of South Dum Dum		
Year	Pop.	Growth $\pm\%$
1901	10,904	—
1911	12,874	+18.1%
1921	14,030	+9.0%
1931	18,471	+31.7%
1941	25,838	+39.9%
1951	61,391	+137.6%
1961	111,284	+81.3%
1971	174,342	+56.7%
1981	230,266	+32.1%
1991	232,811	+1.1%
2001	392,444	+68.6%
2011	403,316	+2.8%
2021	436,387	+8.2%

The every 10th year wise population of South dum dum municipality is shown above . Also the growth rate of population is mentioned . This gives us a clear idea about the demography of South dum dum municipality .

PRAMOD NAGAR DUMPING YARD

This study was conducted in Pramod nagar Waste Disposal Site, Dum Dum and its associated area (nearly 60 acres/ 24 hectare) (Lat 22.6462°N and Long 88.3958°E) of Kolkata metropolitan city, West Bengal (Shown in Figure). Pramodnagar is used as a solid waste disposal site for six municipalities (South Dum Dum, Dum Dum, North Dum Dum, New Barrackpore, Baranagar and Kamarhati) and dumping municipal garbage (600 metric tons approximately/day) regularly, those constitute household garbage, sludge and biomedical wastes. Diversity of landscape, heap of garbage, unpleasant decaying smell, heavy smoke (waste material The main waste dumping site is bordered from three sides by a waste water canal, which in turns encircled by canal side plantations and few colonies for human habitation and a fresh water pond is also situated in close vicinity to the dumping ground . [32]

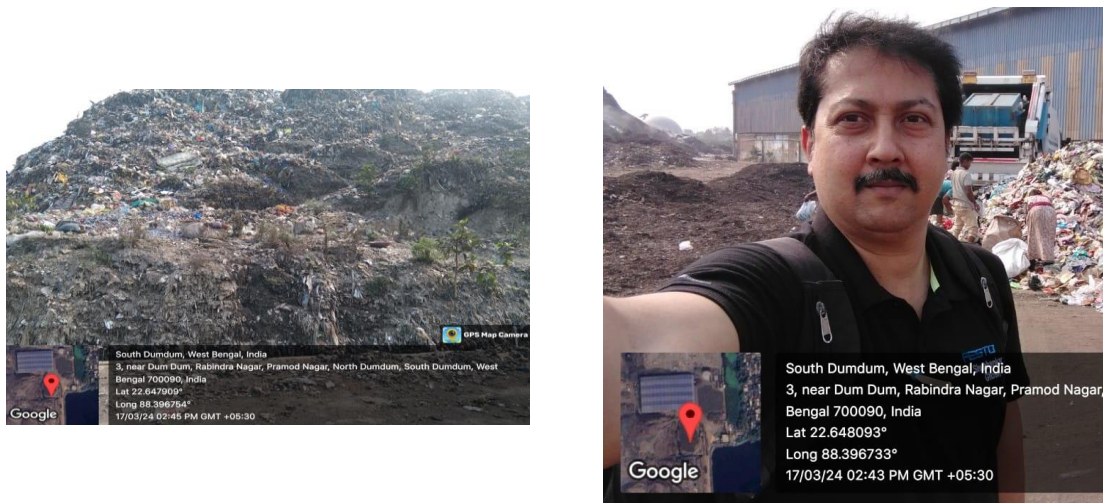


Figure 4.4 – Solid waste sample collection (Source : Pramod nagar dumping yard , dt. – 17.3.2024.)

4.5 PHYSICAL PARAMETERS OF MSW:

Sample which was collected from Pramod Nagar disposal site was taken to laboratory and was segregated into garbage, paper, plastic, glass etc. manually. Then the different type of the segregated amount was weighed and expressed as percentage of the initial amount of solid waste . Then the percentage of each part was calculated .



Figure 4.5 – Waste sample segregation (Sorce Pramod nagar dumping yard solid waste sample collected on 17.3.24.)

4.6 CHEMICAL PARAMETER ANALYSIS :

MOISTURE CONTENT :
(DRY MASS METHOD)

The moisture content in a solid waste sample is determined by drying a known quantity of sample in hot air oven at 105°C and estimating the loss of weight. The apparatus needed for determination of moisture content are Petri dish, balance and desiccator. A clean and empty Petri dish should be replaced in a hot air oven at 105°C for 30 minutes. After that it should be removed and cooled in a desiccator and then weight accurately. The Petri dish should then be filled to about two third of its capacity with the fresh sample of solid waste and weighs quickly. After that, dish with sample should be kept in oven at 105°C for 8 hours. After the expiry of time, the dish should be removed, cooled in desiccator and weight quickly.

The loss in weight is then calculated and moisture content is expressed on oven dry basis. The percentage moisture content is calculated as:

$$\text{Moisture content (\%)} = \frac{b - c}{b - a} \times 100$$

Where, a = wt. of empty dish, gm

b = wt. of dish + sample, gm

c = wt. of dish + sample after drying, gm .

4.7 ORGANIC CARBON DETERMINATION (Walkley and Black, 1934) :

In this process the organic carbon is oxidized with potassium dichromate ($K_2Cr_2O_7$) in presence of concentrated H_2SO_4 which produces nascent oxygen, with carbosuf which organic matter to produce CO_2 The remaining volume of $K_2Cr_2O_7$ is titrated against the standard solution of Ferrous Ammonium Sulphate in of phosphoric acid (H_3PO_4) and Diphenylamine indicator, and thus the volume of $K_2Cr_2O_7$ can be found out which actually required to oxidize organic carbon.

4.7.1 Reagents:

1. 1 N $K_2Cr_2O_7$ (dissolve 49.04 gm in 1 litre distilled water)
2. 0.5N Ferrous Ammonium Sulphate (dissolve 32 gm of $(NH_4)_2SO_4$ $FeSO_4 \cdot 6H_2O$ water containing 20 ml conc. H_2SO_4 and dilute to 2 litre.)
3. Conc. H_2SO_4
4. Conc. Ortho-phosphoric acid

5. Indicator (dissolve 0.5 gm Diphenylamine in 20 ml water + 100 ml conc. H_2SO_4)

4.7.2 Procedure:

Take 1 gm of solid waste sample in a 500 ml conical flask and add 10 ml $\text{K}_2\text{Cr}_2\text{O}_7$ and 20 ml conc. H_2SO_4 the whole content by gentle rotation for one minute, to ensure complets contact of the reagent with the sample. Allow the mixture to stand for 30 minutes. After this time, add about 200 ml of water, 10 ml of phosphoric acid and 1 ml of indicator solution (colour of the mixture will turn blue). After titrate the remaining amount of $\text{I NK}_2\text{Cr}_2\text{O}_7$ with 0.5 N FAS until the colour changes to brilliant green.[33]

4.7.3 Calculations:

% carbon in sample $(B-T) \times S \times 0.003 \times 100 / \text{weight of sample}$

Where, B = titrate value of blank

T = titrate value with sample

4.8 DETERMINATION OF CALORIFIC VALUE BY BOMB CALORIMETER



Figure 4.6 – Bomb calorimeter (Source – Sadguru laboratory , Nager bazar – Kolkata – 700028)

A bomb calorimeter is a type of constant-volume calorimeter used in measuring the heat of combustion of a particular reaction. Bomb calorimeters have to withstand the large pressure within the calorimeter as the reaction is being measured. Electrical energy is used to ignite the fuel; as the fuel is burning, it will heat up the surrounding air, which expands and escapes through a tube that leads the air out of the calorimeter. When the air is escaping through the copper tube it will also heat up the water outside the tube. The change in temperature of the water allows for calculating calorie content of the fuel.[34]

In more recent calorimeter designs, the whole bomb, pressurized with excess pure oxygen (typically at 30 standard atmospheres (3,000 kPa)) and containing a weighed mass of a sample (typically 1–1.5 g) and a small fixed amount of water (to saturate the internal atmosphere, thus ensuring that all water produced is liquid, and removing the need to include enthalpy of vaporization in calculations), is submerged

under a known volume of water (ca. 2000 ml) before the charge is electrically ignited. The bomb, with the known mass of the sample and oxygen form combustion and heat flow from this crosses the stainless steel wall, thus raising the temperature of the steel bomb, its contents, and the surrounding water jacket. The temperature change in the water is then

accurately measured with a thermometer. This reading, along with a bomb factor (which is dependent on the heat capacity of the metal bomb parts), is used to calculate the energy given out by the sample burn. A small correction is made to account for the electrical energy input, the burning fuse, and acid production (by titration of the residual liquid). After the temperature rise has been measured, the excess pressure in the bomb is released.

Basically, a bomb calorimeter consists of a small cup to contain the sample, oxygen, a stainless steel bomb, water, a stirrer, a thermometer, the dewar or insulating container (to prevent heat flow from the calorimeter to the surroundings) and ignition circuit connected to the bomb. By using stainless steel for the bomb, the reaction will occur with no volume change observed.

Since there is no heat exchange between the calorimeter and surroundings ($Q = 0$) (adiabatic), no work is performed ($W = 0$) .

4.8.1 PROCEDURE :

At first take weight of the crucible. Then take approximate 1 gm of solid waste sample. Collect a piece of Nichrome wire tightly across the terminals of the cotton so the they touch the sample. Put distilled water in bomb assembles the bomb and charge it slow, with oxygen to a pressure of 30 atm without placing the original air. Our 2.5 litre distilled water in calorimeter vessel to cover the flat upper surface of bomb cap. This quantity of water should be the same, within 1 gm as that used in determining the mean effect heat capacity. Pour sufficient distilled water into the water jacket. Transfer the calorimeter vessel to water jacket, lower the bomb into the calorimeter vessel and check that the bomb is gas tight. Connect the red and black pin into the bomb head from the fringe unit. Motor plug put on the proper position of the firing unit. Now on the main switch. After 5 minutes note the actual temperature through the digital display. That is preliminary period (T1). Then close the circus to fire the change by push switch of the firing unit and observe the temperature after 10-12 minutes. Note down the

temperature that is the chief period (T2). After completion of the experiment off the main switch, put off the digital temperature indicator also. Remove the bomb calorimeter vessel, release the pressure and dismantle the bomb. Examine the bomb interior and discard the test if unburned samples are found. Then calculate the calorific value.[35]

4.8.2 CALCULATION :

Calorific value water equivalent rising temperature (T2-T1)

Where,

T1 = initial temperature (preliminary period)

T2 = final temperature (chief period)



Figure 4.7 Bomb with sample holder (Source – Sadguru laboratory , Nager bazar – Kolkata – 700028)

5. RESULT & DISCUSSION

5.1 PHYSICAL & CHEMICAL PROPERTY ANALYSIS OF MSW FROM COMPACTOR M/C.

Table 5.1- Physical properties of MSW
(Sample no. 1 from south dum dum municipal compactor machine)

PARAMETERS	UNIT	RESULT
Garbage (Organic)	%	54.52
Ash / Earth	%	3.88
Paper / Cupboard	%	4.56
Plastic / PVC	%	9.56
Rapper / Cotton	%	4.76
Rubber	%	-
Leather	%	0.86
Wood	%	3.45
Earthenware	%	0.89
Ceramics	%	-
Glass	%	0.36
Hay / Straw / Thermocol	%	15.76
Leaves	%	0.83
Metals	%	0.32
Others	%	0.25
Bulk Density	gm/cc	1.85
Specific Gravity	-	1.854

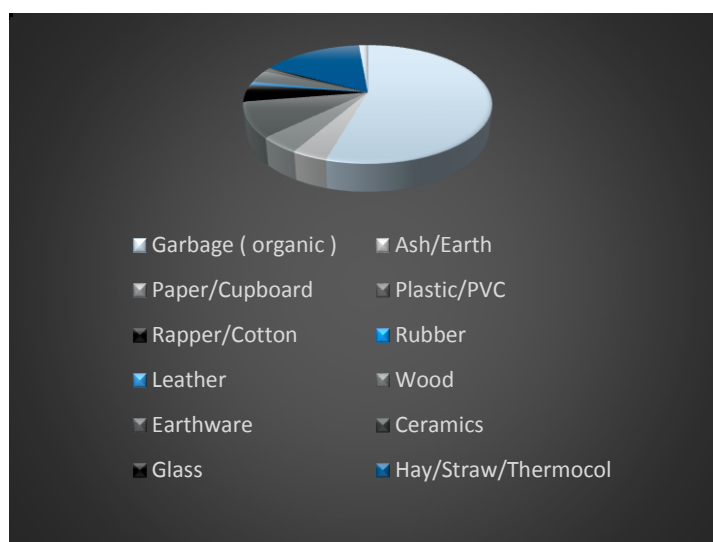


Figure 5.1- Pictorial representation of MSW (Source compactor m/c. – sample 1)

Table 5.2 - Chemical properties of MSW(Sample no. 1 from south dum dum municipal compactor machine)

Parameters	Results
Moisture Content (%)	34.8
Total Carbon (%)	25.2
Potassium, mg / kg	333
Net Calorific Value, kcal / kg	1287

Table 5.3 -Physical properties of MSW
(Sample no. 2 from south dum dum municipal compactor machine)

PARAMETERS	UNIT	RESULT
Garbage (Organic)	%	50.22
Ash / Earth	%	4.11
Paper / Cupboard	%	5.67
Plastic / PVC	%	9.50
Rapper / Cotton	%	4.50
Rubber	%	0.25
Leather	%	0.80
Wood	%	3.45
Earthenware	%	1.50
Ceramics	%	-
Glass	%	0.56
Hay / Straw / Thermocol	%	16.24
Leaves	%	1.20
Metals	%	1.50
Others	%	0.50
Bulk Density	gm/cc	1.75
Specific Gravity	-	1.75

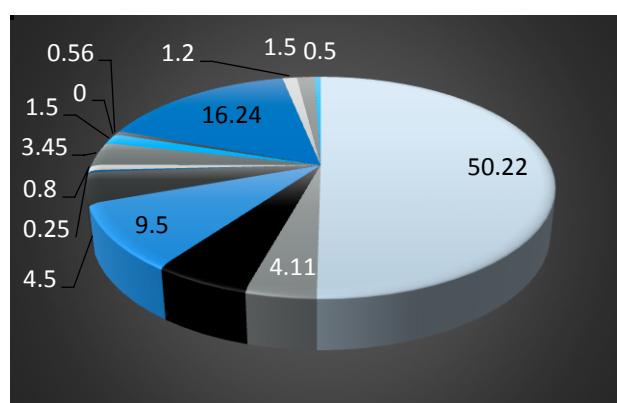
**Figure 5.2- Pictorial representation of MSW (Source compactor m/c. – sample 2)**

Table – 5.4 - Chemical properties of MSW
(Sample no. 2 from south dum dum municipal compactor machine)

Parameters	Results
Moisture Content (%)	36.8
Total Carbon (%)	27.9
Potassium, mg / kg	351
Net Calorific Value, kcal / kg	1377

Table – 5.5 - Physical properties of MSW
(Sample no. 3 from south dum dum municipal compactor machine)

PARAMETERS	UNIT	RESULT
Garbage (Organic)	%	58.20
Ash / Earth	%	4.88
Paper / Cupboard	%	4.92
Plastic / PVC	%	9.50
Rapper / Cotton	%	4.70
Rubber	%	0.30
Leather	%	0.56
Wood	%	1.94
Earthenware	%	0.80
Ceramics	%	-
Glass	%	0.20
Hay / Straw / Thermocol	%	11.76
Leaves	%	1.20
Metals	%	0.80
Others	%	0.24
Bulk Density	gm/cc	1.89
Specific Gravity	-	1.891

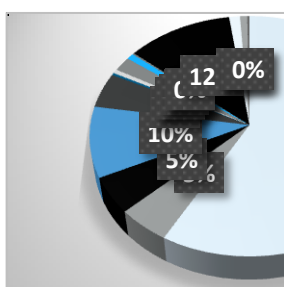


Figure 5.3- Pictorial representation of MSW (Source - compactor m/c. – sample 3)

Table – 5.6 -Chemical properties of MSW
(Sample no 3 from south dum dum municipal compactor machine)

Parameters	Results
Moisture Content (%)	32.1
Total Carbon (%)	2.2
Potassium, mg /kg	313
Net Calorific Value, kcal /kg	1337

Table – 5.7 Physical properties of MSW
(Sample no. 4 from south dum dum municipal compactor machine)

PARAMETERS	UNIT	RESULT
Garbage (Organic)	%	52.62
Ash / Earth	%	5.88
Paper / Cupboard	%	4.60
Plastic / PVC	%	10.50
Rapper / Cotton	%	3.50
Rubber	%	-
Leather	%	1.25
Wood	%	3.75
Earthenware	%	2.50
Ceramics	%	0.50
Glass	%	0.30
Hay / Straw / Thermocol	%	11.76
Leaves	%	0.84
Metals	%	0.32
Others	%	1.68
Bulk Density	gm/cc	1.75
Specific Gravity	-	1.752

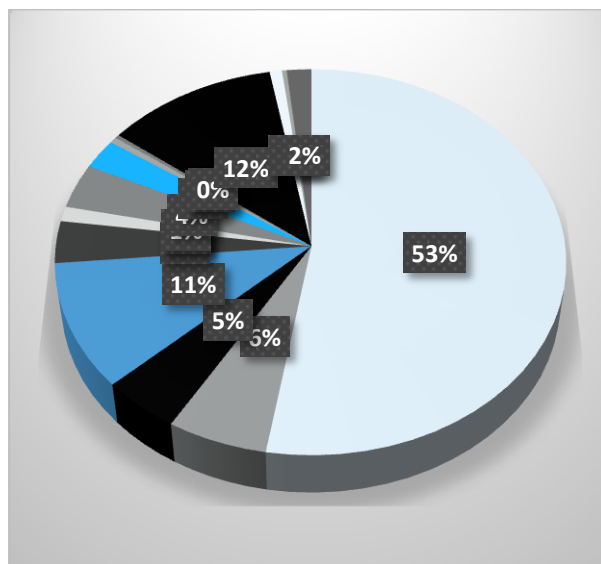


Figure 5.4- Pictorial representation of MSW (Source -Compactor m/c. – sample 4)

Table – 5.8 - Chemical properties of MSW
(Sample no. 4 from south dum dum municipal compactor machine)

Parameters	Results
Moisture Content (%)	30.8
Total Carbon (%)	29.2
Potassium, mg /kg	303
Net Calorific Value, kcal / kg	1410

5.2 PHYSICAL & CHEMICAL PROPERTY ANALYSIS OF MSW FROM DUMPING YARD

Table- 5.9 - Physical properties of MSW
(Sample no.1 from pramod nagar dumping yard)

PARAMETERS	UNIT	RESULT
Garbage (Organic)	%	60.50
Ash / Earth	%	4.20
Paper / Cupboard	%	4.50
Plastic / PVC	%	7.50
Rapper / Cotton	%	4.30
Rubber	%	-
Leather	%	0.86
Wood	%	3.14
Earthenware	%	1.50
Ceramics	%	-
Glass	%	0.50
Hay / Straw / Thermocol	%	11.25
Leaves	%	0.75
Metals	%	0.32
Others	%	0.68
Bulk Density	gm/cc	1.95
Specific Gravity	-	1.952

Table – 5.10 Chemical properties of MSW
(Sample no. 1 from Pramod nagar dumping yard)

Parameters	Results
Moisture Content (%)	30.8
Total Carbon (%)	29.2
Potassium, mg /kg	303
Calorific Value, kcal / kg	1429

Table – 5.11 Physical properties of MSW
(Sample no. 2 from Pramod nagar dumping yard)

PARAMETERS	UNIT	RESULT
Garbage (Organic)	%	59.52
Ash / Earth	%	4.54
Paper / Cupboard	%	4.56
Plastic / PVC	%	11.38
Rapper / Cotton	%	4.75
Rubber	%	0.25
Leather	%	0.50
Wood	%	3.45
Earthenware	%	1.05
Ceramics	%	-
Glass	%	0.44
Hay / Straw / Thermocol	%	7.78
Leaves	%	1.06
Metals	%	0.32
Others	%	0.40
Bulk Density	gm/cc	1.99
Specific Gravity	-	1.99

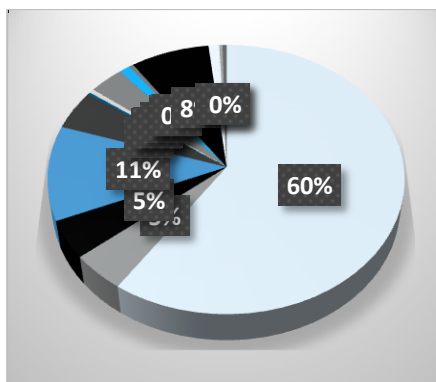


Figure 5.5- Pictorial representation of MSW (Source – sample 2)

Table – 5.12 Chemical properties of MSW
(Sample no. 2 from Pramod nagar dumping yard)

Parameters	Results
Moisture Content (%)	34.1
Total Carbon (%)	28.2
Potassium, mg /kg	283
Net Calorific Value, kcal / kg	1499

Table – 5.13 Physical properties of MSW
(Sample no. 3 from Pramod nagar dumping yard)

PARAMETERS	UNIT	RESULT
Garbage (Organic)	%	60.60
Ash / Earth	%	4.12
Paper / Cupboard	%	4.28
Plastic / PVC	%	10.50
Rapper / Cotton	%	3.76
Rubber	%	-
Leather	%	0.74
Wood	%	4.50
Earthenware	%	1.89
Ceramics	%	-
Glass	%	0.31
Hay / Straw / Thermocol	%	8.80
Leaves	%	0.43
Metals	%	0.32
Others	%	0.25
Bulk Density	gm/cc	1.88
Specific Gravity	-	1.882

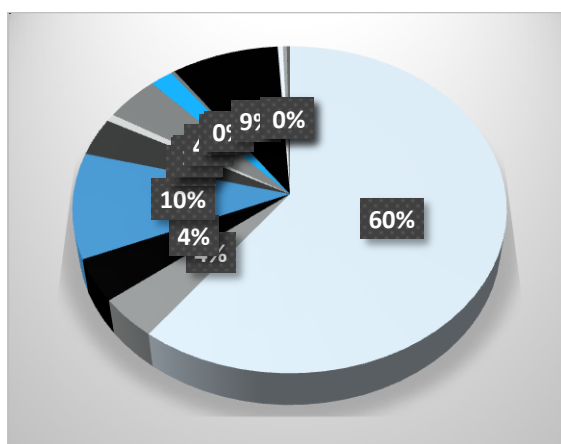


Figure 5.6- Pictorial representation of MSW (ref. Dumping yard . – sample 3)

Table – 5.14 Chemical properties of MSW
(Sample no. 3 from Pramod nagar dumping yard)

Parameters	Results
Moisture Content (%)	37.3
Total Carbon (%)	29.2
Potassium, mg / kg	293
Net Calorific Value, kcal / kg	1357

Table – 5.15 Physical properties of MSW
(Sample no. 4 from Pramod nagar dumping yard)

PARAMETERS	UNIT	RESULT
Garbage (Organic)	%	48.52
Ash / Earth	%	4.88
Paper / Cupboard	%	6.60
Plastic / PVC	%	13.50
Rapper / Cotton	%	4.70
Rubber	%	-
Leather	%	0.30
Wood	%	4.50
Earthenware	%	0.90
Ceramics	%	-
Glass	%	0.60
Hay / Straw / Thermocol	%	12.76
Leaves	%	0.74
Metals	%	0.75
Others	%	1.25
Bulk Density	gm/cc	1.81
Specific Gravity	-	1.81

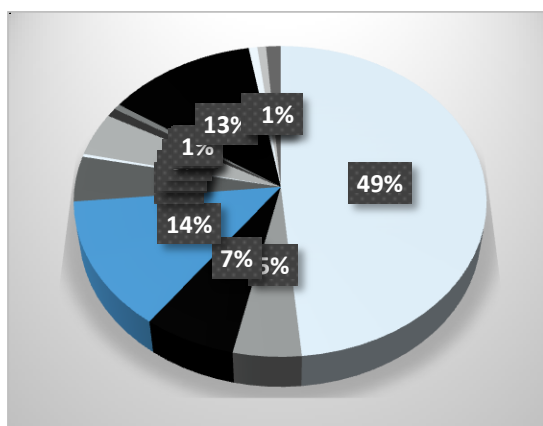


Figure 5.7- Pictorial representation of MSW (Souce - dumping yard . – sample 4)

Table 5.16 -Chemical properties of MSW
(Sample no. 4 from Pramod nagar dumping yard)

Parameters	Results
Moisture Content (%)	30.8
Total Carbon (%)	31.2
Potassium, mg / kg	353
Net Calorific Value, kcal / kg	1399

Table 5.17 - Physical properties of MSW
(Sample no. 5 from Pramod nagar dumping yard)

PARAMETERS	UNIT	RESULT
Garbage (Organic)	%	55.57
Ash / Earth	%	4.02
Paper / Cupboard	%	3.41
Plastic / PVC	%	13.50
Rapper / Cotton	%	4.20
Rubber	%	-
Leather	%	0.80
Wood	%	4.45
Earthenware	%	1.52
Ceramics	%	-
Glass	%	0.33
Hay / Straw / Thermocol	%	10.70
Leaves	%	0.83
Metals	%	0.50
Others	%	0.17
Bulk Density	gm/cc	1.82
Specific Gravity	-	1.822

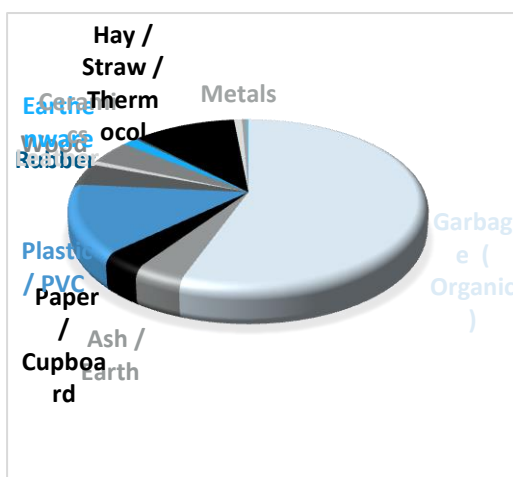


Figure 5.8- Pictorial representation of MSW (Source - dumping yard . – sample 5)

Table – 5.18 Chemical properties of MSW
(Sample no. 5 from Pramod nagar dumping yard)

Parameters	Results
Moisture Content (%)	32.3
Total Carbon (%)	27.6
Potassium, mg / kg	291
Net Calorific Value, kcal /kg	1455

Table – 5.19 Physical properties of MSW
(Sample no. 6 from Pramod nagar dumping yard)

PARAMETERS	UNIT	RESULT
Garbage (Organic)	%	53.51
Ash / Earth	%	4.88
Paper / Cupboard	%	6.61
Plastic / PVC	%	10.20
Rapper / Cotton	%	4.76
Rubber	%	-
Leather	%	1.04
Wood	%	3.70
Earthenware	%	1.20
Ceramics	%	-
Glass	%	0.30
Hay / Straw / Thermocol	%	12.50
Leaves	%	0.80
Metals	%	0.22
Others	%	0.28
Bulk Density	gm/cc	1.91
Specific Gravity	-	1.911

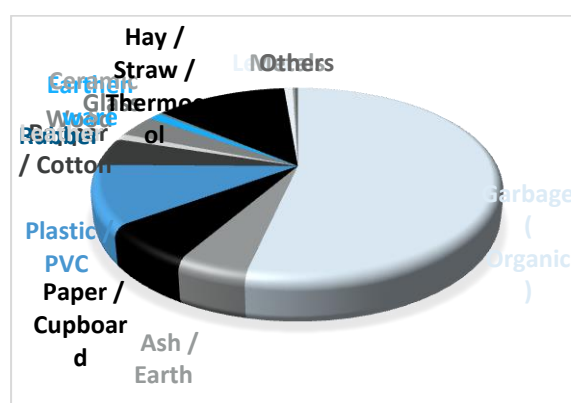


Figure 5.9- Pictorial representation of MSW (Souce- dumping yard . – sample 6)

Table – 5.20 Chemical properties of MSW
(Sample no. 6 from Pramod nagar dumping yard)

Parameters	Results
Moisture Content (%)	31.4
Total Carbon (%)	21.2
Potassium, mg / kg	273
Net Calorific Value, kcal /kg	1489

Table – 5.21 Physical properties of MSW
(Sample no. 7 from Pramod nagar dumping yard)

PARAMETERS	UNIT	RESULT
Garbage (Organic)	%	56.80
Ash / Earth	%	3.80
Paper / Cupboard	%	4.44
Plastic / PVC	%	12.96
Rapper / Cotton	%	3.50
Rubber	%	-
Leather	%	1.20
Wood	%	3.25
Earthenware	%	0.75
Ceramics	%	-
Glass	%	0.80
Hay / Straw / Thermocol	%	10.20
Leaves	%	1.75
Metals	%	0.30
Others	%	0.25
Bulk Density	gm/cc	1.89
Specific Gravity	-	1.89

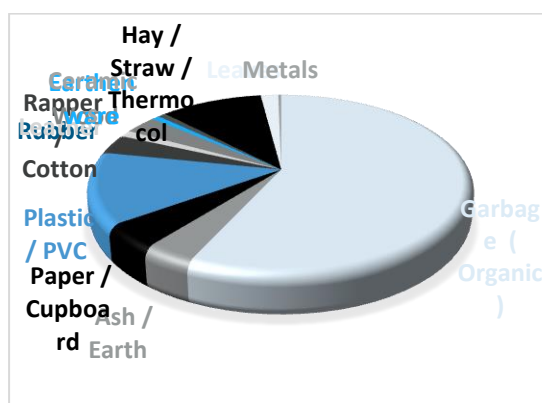


Figure 5.10- Pictorial representation of MSW (Source- dumping yard . – sample 7)

Table – 5.22 - Chemical properties of MSW
(Sample no. 7 from Pramod nagar dumping yard)

Parameters	Results
Moisture Content (%)	30.2
Total Carbon (%)	21.2
Potassium, mg / kg	313
Net Calorific Value, kcal / kg	1495

Table – 5.23 - Physical properties of MSW
(Sample no. 8 from Pramod nagar dumping yard)

PARAMETERS	UNIT	RESULT
Garbage (Organic)	%	58.82
Ash / Earth	%	4.88
Paper / Cupboard	%	5.30
Plastic / PVC	%	11.50
Rapper / Cotton	%	4.30
Rubber	%	-
Leather	%	0.70
Wood	%	3.50
Earthenware	%	0.89
Ceramics	%	-
Glass	%	0.61
Hay / Straw / Thermocol	%	8.10
Leaves	%	0.75
Metals	%	0.40
Others	%	0.25
Bulk Density	gm/cc	1.87
Specific Gravity	-	1.876

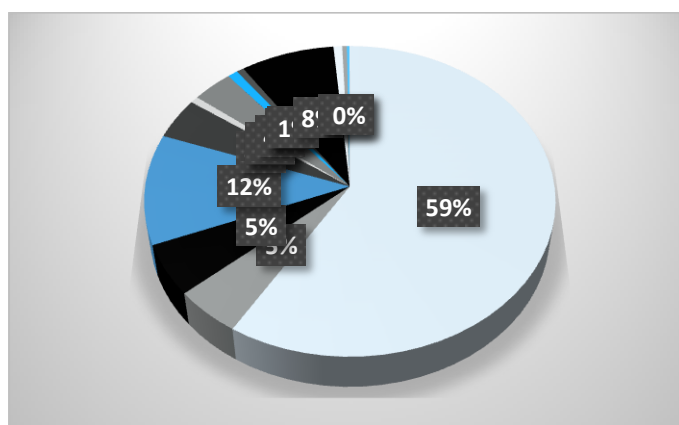


Figure 5.11- Pictorial representation of MSW (Source -dumping yard . – sample 8)

Table – 5.24 - Chemical properties of MSW
(Sample no. 8 from Pramod nagar dumping yard)

Parameters	Results
Moisture Content (%)	35.6
Total Carbon (%)	29.2
Potassium, mg / Kg	321
Net Calorific Value, K Cal / Kg	1467

Table 5.25 - Physical properties of MSW
(Sample no. 9 from Pramod nagar dumping yard)

PARAMETERS	UNIT	RESULT
Garbage (Organic)	%	50.52
Ash / Earth	%	4.18
Paper / Cupboard	%	4.30
Plastic / PVC	%	10.50
Rapper / Cotton	%	4.80
Rubber	%	-
Leather	%	0.70
Wood	%	5.50
Earthenware	%	1.50
Ceramics	%	.40
Glass	%	0.60
Hay / Straw / Thermocol	%	15.19
Leaves	%	0.84
Metals	%	0.52
Others	%	0.45
Bulk Density	gm/cc	1.91
Specific Gravity	-	1.911

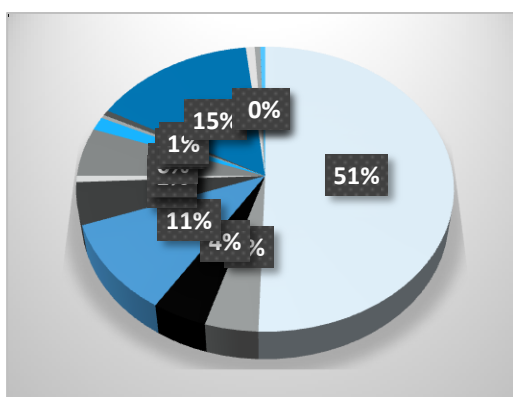


Figure 5.12- Pictorial representation of MSW (Source - dumping yard . – sample 9)

Table – 5.26 - Chemical properties of MSW
(Sample no. 9 from Pramod nagar dumping yard)

Parameters	Results
Moisture Content (%)	33.5
Total Carbon (%)	29.2
Potassium, mg / kg	249
Net Calorific Value , kcal / kg	1399

Table 5.27- Physical properties of MSW
(Sample no. 10 from Pramod nagar dumping yard)

PARAMETERS	UNIT	RESULT
Garbage (Organic)	%	58.53
Ash / Earth	%	3.49
Paper / Cupboard	%	4.98
Plastic / PVC	%	14.50
Rapper / Cotton	%	4.70
Rubber	%	-
Leather	%	0.80
Wood	%	3.15
Earthenware	%	0.80
Ceramics	%	-0.3
Glass	%	0.36
Hay / Straw / Thermocol	%	7.01
Leaves	%	0.63
Metals	%	0.36
Others	%	0.55
Bulk Density	gm/cc	1.93
Specific Gravity	-	1.931

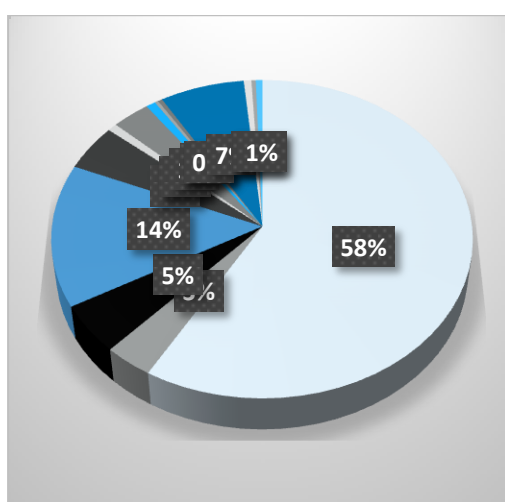


Figure 5.13- Pictorial representation of MSW (Source- dumping yard . – sample 10)

Table 5.28 - Chemical properties of MSW
(Sample no. 10 from Pramod nagar dumping yard)

Parameters	Results
Moisture Content (%)	30.1
Total Carbon (%)	30.2
Potassium, mg / kg	293
Net Calorific Value, kcal / kg	1486

5.3 AVERAGE OF NET CALORIFIC VALUE OF MSW

From the different samples of Pramod Nagar dumping yard , the average net calorific value is calculated and furnished in the below table .

Table – 5.29 – Average net calorific value

SAMPLE NO.	NET CALORIFIC VALUE(K Cal / Kg)
1.	1429
2.	1499
3.	1357
4.	1399
5.	1455
6.	1489
7.	1495
8.	1467
9.	1399
10.	1486
AVG. NET CALORIFIC VALUE	1447.5

All the collected samples were perfectly verified , both physically and chemically were tested. As per the test report it is evident that samples are containing less than 50% moisture and the calorific value is more than 1200 kcal/kg. We know that if moisture content is less than 50% in a specific sample , It will be good enough for energy harvesting.

5.4 REPRESENTATION OF CALORIFIC VALUE IN BAR CHART

So the average net calorific value of the waste generated in South Dum Dum Municipality which is being dumped in Pramod Nagar Dumping Yard is approximately **1447.5 K Cal / Kg** . From the municipality data of North 24 Pgs., we can get the per day solid waste generated value and thus multiplying it with the average calorific value we will get probable heat energy generation value from South Dum Dum Municipality Solid waste .

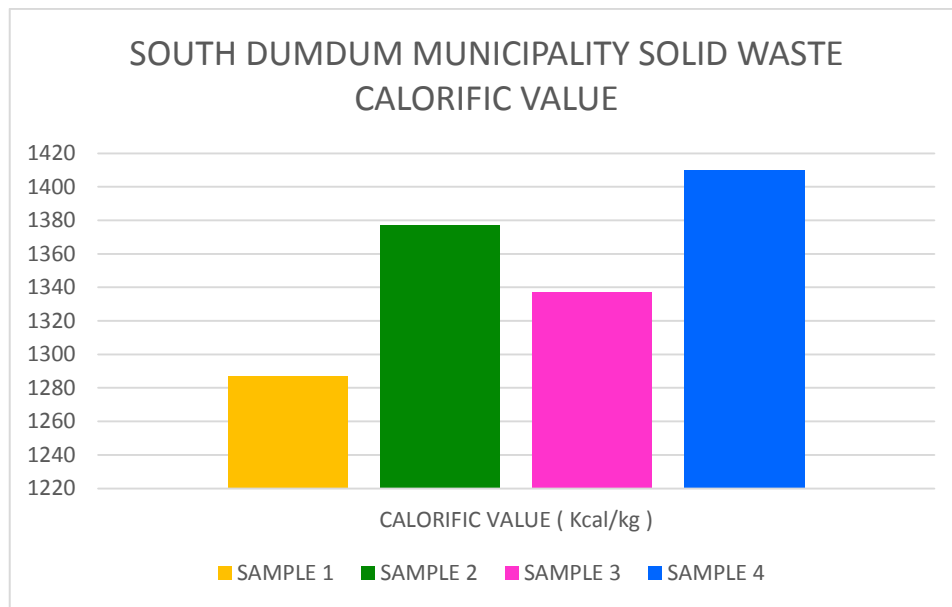


Figure 5.14 – Calorific value of MSW sample of compactor m/c (Source – South dum dum , ward no. 18)

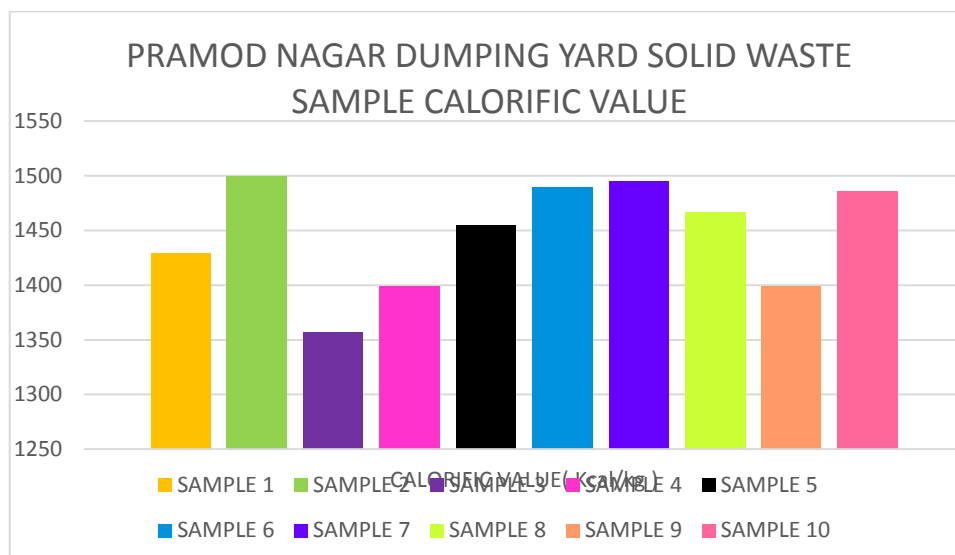


Figure 5.15 – Calorific value of MSW sample of dumping yard (Source – Pramod nagar dumping yard)

5.5 MUNICIPALITY SOLID WASTE DATA OF NORTH 24 PARGANA

Table – 5.30 - Municipal solid waste generation data

Urban Local bodies		No of Wards	No of Households	Population	Solid Waste Generated per day (MT)
Municipal corporations	Ashokenagar-Kalyangarh	23	32336	135592	78.4
(North 24 Pgs.)	Baduria	17	12065	52493	13.62
	Baranagar	34	84600	292637	150
	Barasat	35	109874	278435	130
	Barrackpore	24	37656	152783	50
	Basirhat	23	43996	153984	35
	Bhatpara	35	163428	480523	205
	BMC	41	153661	634106	400
	Bongaon	22	29680	119340	65
	Dum Dum	22	27702	114786	62.1
	Garulia	21	18122	85336	35
	Gayeshpur	NA	NA	NA	NA
	Gobardanga	17	12615	45377	16
	Habra	24	36016	147221	72
	Halisahar	23	33613	124939	52
	Kamarhati	35	80000	331163	150
	Kanchrapara	24	27976	129576	56.71
	Khardah	22	26000	108496	64.5
	Madhyamgram	28	70000	240000	82
	Naihati	31	36447	217900	165
	New Barrackpore	20	16725	76846	29.06
	N. Barrackpore	23	32564	132806	59.7
	North Dum Dum	34	64471	249142	150
	Panihati	35	94000	469000	196
	S. Dum Dum	35	103741	403316	578
	Taki	16	8919	38263	83.63
	Titagarh	23	23869	116520	65

Source : Survey report of North 24 Pgs. Municipality area

No. of wards , house holds , population and per day solid waste generation is illustrated in the above table for North 24 Pgs. Out of this , we have considered South Dum Dum municipality for our reference and study .

5.6 FINDING FROM THE STUDY

From the above Table it is evident that the solid waste generated in South Dum Dum Municipality is **578 MT** , which is equal to **578000 Kg**.

We have evaluated the net average calorific value of South Dum Dum Municipality area and it is **1447.5 kcal / Kg** .

So , the per day heat energy generation possibility in South Dum Dum Municipality area by using the Municipal Solid Waste with incineration process is

$$= (578000 \times 1447.5) \text{ K Cal .} = \mathbf{836655 \times 10^3 \text{ kcal .}}$$

So , per month heat energy generation possibility in South Dum Dum Municipality area by using the Municipal Solid Waste with incineration process is

$$= (836655 \times 10^3 \times 30) \text{ kcal} = \mathbf{25099.65 \times 10^6 \text{ kcal .}}$$

So , yearly heat energy generation possibility in South Dum Dum Municipality area by using the Municipal Solid Waste with incineration process is

$$= (25099.65 \times 10^6 \times 12) \text{ kcal} = \mathbf{301.1958 \times 10^9 \text{ kcal .}}$$

Now , utilising this heat energy we can generate steam and further that can be utilised for the generation of electricity in power plants. We should observe that by utilising this heat how much steam can be generated and how much electricity can be generated .This will give us a suitable idea about the saving of coal in power plants. In next chapter we will discuss the probability of coal saving in Titagarh thermal power plant if we utilise this MSW generated heat energy.

**6. FIELD APPLICATION FOR
PARTIAL
REPLACEMENT OF COAL ENERGY
BY
INCINERATED WASTE ENERGY IN
ELECTRICITY GENERATION : A
PROPOSED CASE STUDY**

6.0 A CASE STUDY :

Titagarh Thermal Power Station is a coal-based thermal power plant located at Titagarh in Kolkata city in the Indian state of West Bengal. The power plant is operated by the Calcutta Electric Supply Corporation Limited. It has an installed capacity of 240 Megawatt (4 units x 60 Megawatt). It became fully operational in 1983. Titagarh Thermal Power Station is commissioned in 12 December 1982. The Approved Capacity of the thermal power plant is 240 Megawatt. The installed capacity is also 240 Megawatt. The status of the thermal power plant is Operational. The source of water for the generation of thermal power plant is from Hooghly River. The primary fuel used is coal .

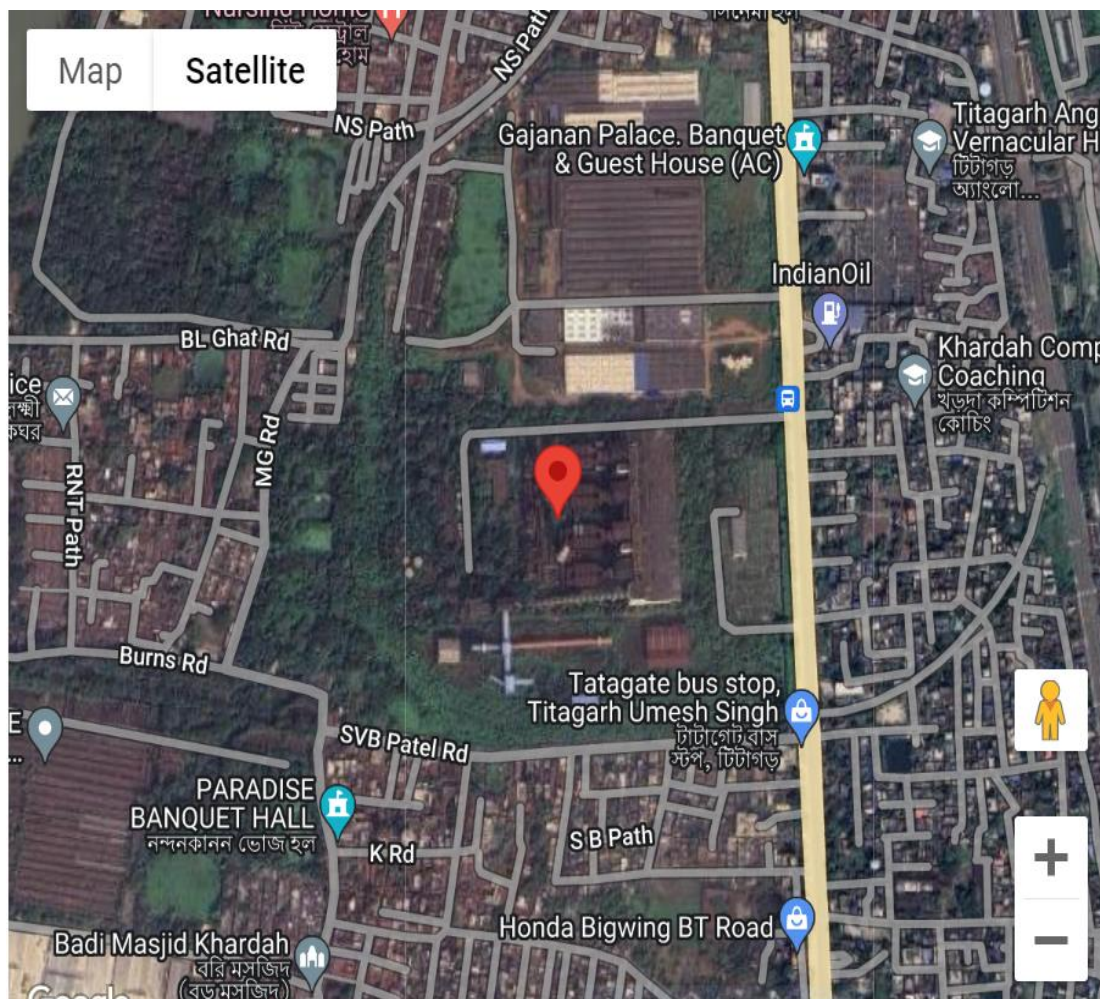
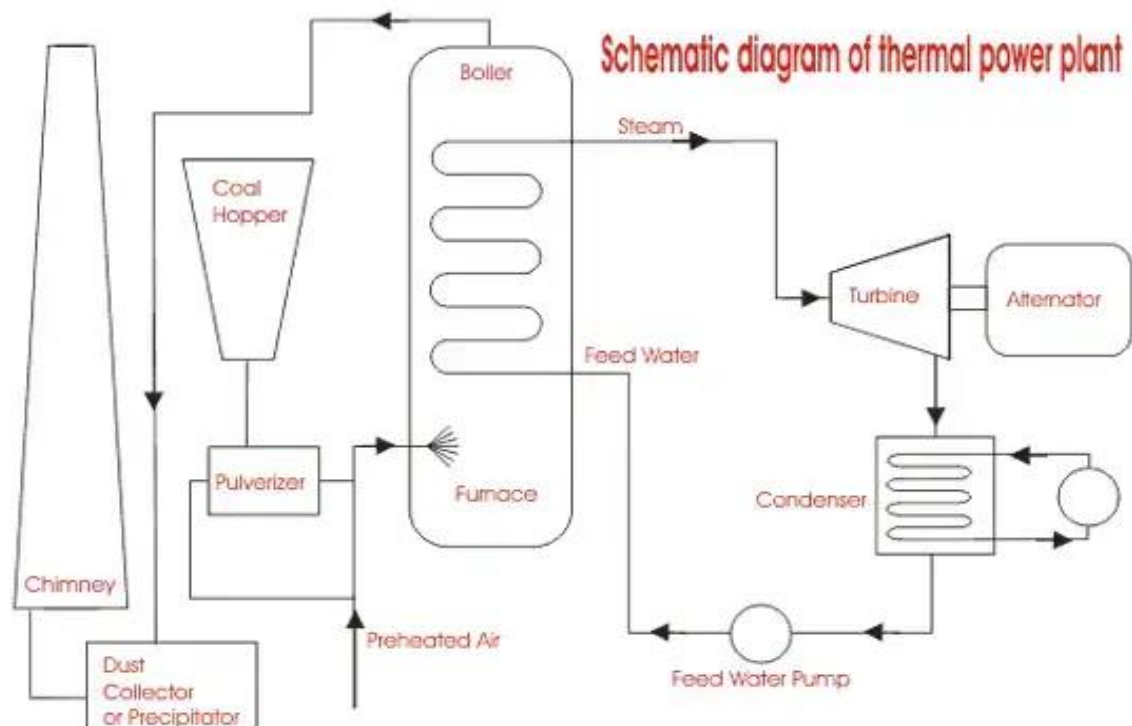


Figure 6.1 study area : Titagarh thermal power plant (Source – google earth)

Total methodology for generating Electricity at this place is described here with relevant data and photographs .

6.1 METHODOLOGY :

1. First, the pulverized coal is burnt into the furnace of steam boiler.
2. High-pressure steam is produced in the boiler.
3. This steam is then passed through the superheater, where it further heated up.
4. This super heated steam is then entered into a turbine at high speed.
5. In turbine, this steam force rotates the turbine blades that means here in the turbine the stored potential energy of the high pressure steam is converted into mechanical energy.



6.2 – Schematic of thermal power plant (Source – Thermal engg. ii – R.S. Khurmi)

6. After rotating the turbine blades, the steam has lost its high pressure, passes out of turbine blades, and enters into a condenser.
7. In the condenser, the cold water is circulated with help of a pump which condenses the low-pressure wet steam.
8. This condensed water is then further supplied to a low-pressure water heater where the low-pressure steam increases the temperature of this feed water, it is then again heated in a high-pressure heater where the high pressure of steam is used for heating.
9. The turbine in the thermal power station acts as a prime mover of the alternator.



Figure 6.3- Power plant (Source - Titagarh thermal power station)

The huge amount of coal is usually supplied through railways. A railway siding line is taken into the power station and the coal is delivered in the storage yard. The coal is unloaded from the point of delivery by means of wagon tippler. It is rack and pinion type. The coal is taken from the unloading site to dead storage by belt conveyors. The belt deliver the coal to 0m level to the pent house and further moves to transfer point 8.

The transfer points are used to transfer coal to the next belt. The belt elevates the coal to breaker house. It consists of a rotary machine, which rotates the coal and separates the light dust from it through the action of gravity and transfer this dust to reject bin house through belt.

The belt further elevates the coal to the transfer point 7 and it reaches the crusher through belt. In the crusher a high-speed 3-phase induction motor is used to crush the coal to a size of 50mm so as to be suitable for milling system. Coal rises from crusher house and reaches the dead storage by passing through transfer point 8.

The direction of the flue gas flow in comparison to the waste transport on the grate is one of the most important factors. The burnout of the gaseous species is very well done in parallel flow geometry, where the flue gas is directed through the hottest zone by a distinctive nose. Also in the parallel flow concept, pyrolysis gases pass through the hottest area and therefore are burnt out satisfactorily. [36]

6.2 REFERENCE DATA FOR THIS SITE :

Table 6.1 - Reference data collected from Titagarh power plant

Plant	Titagarh Thermal Power Station
Installed Capacity in MW	240 Megawatt
Status	Operational
Units operational	4 nos.
Capacity of each unit	4 Units x 60 Megawatt
Boiler manufacturer	Babcock and Wilcox UK
Turbine manufacturer	Parsons UK
Generator manufacturer	Parsons UK
Requirement of coal / day	2,000 – 2,200 ton

Coal Processing for Titagarh power generation :

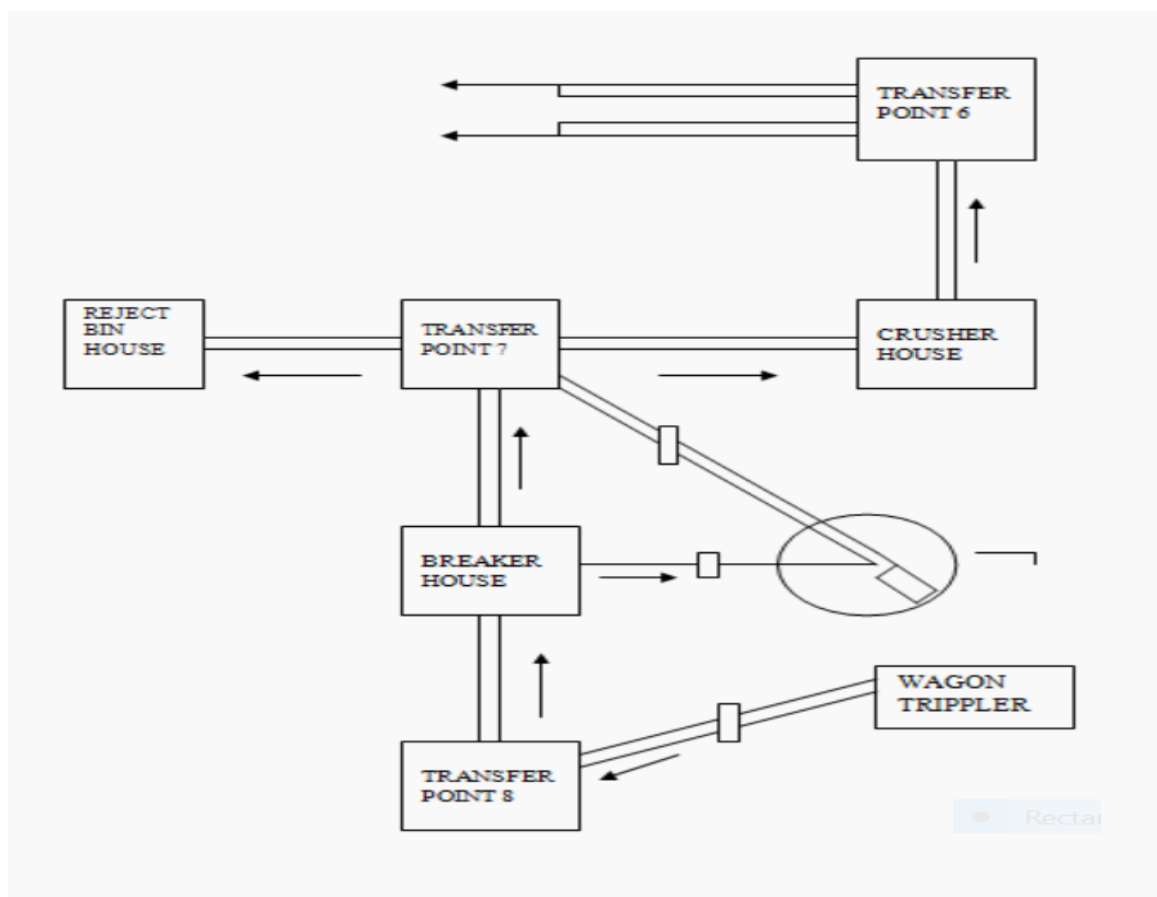


Figure 6.4 – Coal handling application (Source – Thermal engg. – DR. G.K. Vijayaraghavan)

The huge amount of coal is usually supplied through railways. A railway siding line is taken into the power station and the coal is delivered in the storage yard. The coal is

unloaded from the point of delivery by means of wagon tippler. It is rack and pinion type. The coal is taken from the unloading site to dead storage by belt conveyors. The belt deliver the coal to 0m level to the pent house and further moves to transfer point 8.

The transfer points are used to transfer coal to the next belt. The belt elevates the coal to breaker house. It consists of a rotary machine, which rotates the coal and separates the light dust from it through the action of gravity and transfer this dust to reject bin house through belt.

The belt further elevates the coal to the transfer point 7 and it reaches the crusher through belt. In the crusher a high-speed 3-phase induction motor is used to crush the coal to a size of 50mm so as to be suitable for milling system. Coal rises from crusher house and reaches the dead storage by passing through transfer point 8.



Figure 6.5 - Coal handling area (Source - Titagarh thermal power plant)

Coal from the coal wagons is unloaded in the coal handling plant. This unloading is done by the “Tipplers”. This coal is transported up to the raw coal bunkers with the help of conveyor belts.

Crush House

After hand picking foreign material, coal is transported to the Crush house by conveyor belts where it is crushed to small pieces of about 20 mm diameter. The crushed coal is then transported to the store yard. Coal is transported to bowl mills by coal feeders.

Bowl Mill

The coal is pulverized in the bowl mill, where it is grounded to a powder form. The mill consists of a round metallic table on which coal particles fall.

This table is rotated with the help of a motor. There are three large steel rollers, which are spaced 120° apart. When there is no coal, these rollers do not rotate but when the coal is fed to the table it packs up between rollers and the table and this forces the rollers to rotate.

Furnaces

This crushed coal is taken away to the furnace through coal pipes with the help of hot and cold air mixture from P.A Fan. P.A Fan takes atmospheric air, a part of which is sent to Air pre-heaters for heating while a part goes directly to the mill for temperature control.[37]

6.3 EXPECTED BENEFITS OF THIS PROJECT :

Proper handling of waste with improved aesthetic condition .
Savings of coal .
Cost savings .

6.4 ECONOMICAL ANALYSIS :

1 MW electricity can be produced from 3 ton / hr steam .

Now , the full capacity of Titagarh Thermal Power Plant is = 240 MW .

Hence , for generating 240 MW electricity the required steam is
(240 x 3) ton / hr = 720 ton / hr .

So daily requirement of steam = (720 x 24) ton = 17,280 ton .

Now for generating 1 kg steam , required heat energy is 540 kcal .

So , for generating (17,280 x 10³) kg steam , required heat energy is
= (540 x 17,280 x 10³) kcal = 9331200 x 10³ kcal .

The calorific value of the waste sample from Pramod Nagar dumping yard was determined as 1,447.5 kcal / kg .

So, the solid waste required for running Titagarh Thermal Power Plant
is = (9331200 x 10³ / 1447.5) kg
= 6446424.87 kg = 6,446.42 ton .

From the collected site data it is evident that there are 4 operational units .

So , for running each unit the required solid waste per day would be
 $= (6446.42 / 4) \text{ ton} = 1611.605 \text{ ton} .$

But the MSW produced in South Dum Dum Municipality is = 578 ton / day .

So the energy requirement percentage will be fulfilled for each unit per day
 $Is = (578 / 1611.605) \times 100 \% = 35.86 \% = 36 \% \text{ (Approximately)} .$

Now , from site data we get that , for running 4 units of Titagarh Thermal Power plant , requirement of coal is approximately 2000 ton / day .

So for 1 unit , the daily coal requirement is = $(2000 / 4) \text{ ton} = 500 \text{ ton} .$

Hence by using incinerated waste energy from MSW of South Dum Dum Municipality , the per day coal use can be saved by $(500 \times 36 \%) \text{ ton}$
 $= 180 \text{ ton} .$

Accordingly monthly coal consumption can be saved by $(180 \times 30) \text{ ton}$
 $= 5400 \text{ ton} .$

Yearly coal consumption would be saved $(5400 \times 12) \text{ ton} = 64,800 \text{ ton} .$

The synthesis of result is as follows :

SUBSTITUTE OF COAL	DAILY SAVING AMOUNT OF COAL(TON)	MONTHLY SAVING AMOUNT OF COAL(TON)	YEARLY SAVING AMOUNT OF COAL(TON)
MUNICIPAL SOLID WASTE	180	5,400	64,800

7. DESIGN OF INCINERATION PLANT FOR PROVEN TECHNOLOGY

In South Dum Dum Municipality the MSW generated is 578 ton / day . Hence we should design an incineration plant which is more than that capacity . We consider the capacity of the incinerator , say 600 ton / day and design it accordingly .

7.1 Incinerator Selection

Grate Firing Systems for Municipal Waste Incineration

Incinerators can be subdivided into grate firing systems, fluidized bed systems and fixed bed systems. In MSW incineration , grate firing is the commonsystems with a wide distribution and a long-term experience.

Furnace Geometries

Furnace geometry is one of the main features to influence and to optimize the primary combustion. The direction of the flue gas flow in comparison to the waste transport on the grate is one of the most important factors.

Three standard geometries for municipal waste incineration plants have been established and used worldwide :

- (a) Parallel flow,
- (b) Counter flow and,
- (c) Centre flow.

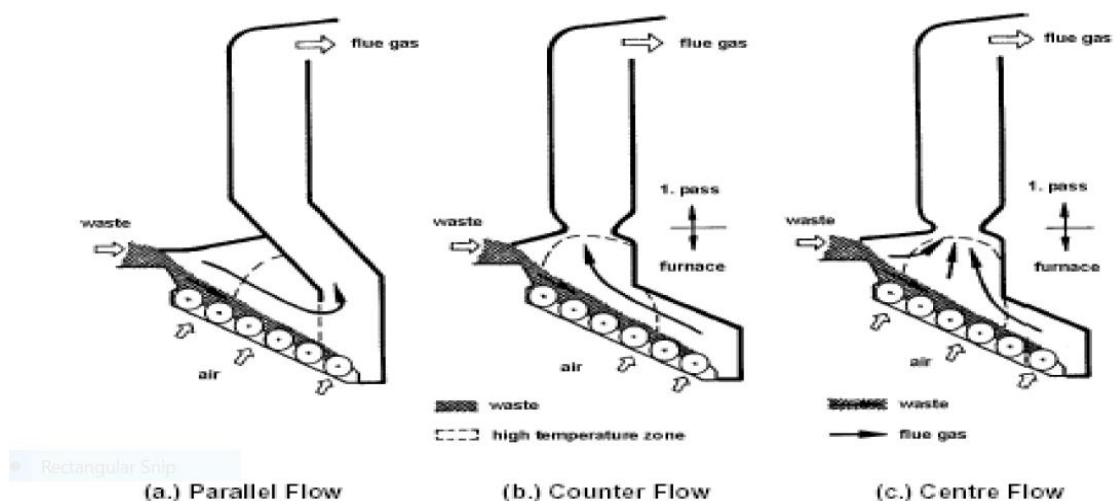


Figure 7.1 – Incinerator geometry (Source – Incineration technology , by Alfons Buckens)

The direction of the flue gas flow in comparison to the waste transport on the grate is one of the most important factors. The burnout of the gaseous species is very well done in parallel flow geometry, where the flue gas is directed through the hottest zone by a distinctive nose. Also in the parallel flow concept, pyrolysis gases pass through the

hottest area and therefore are burnt out satisfactorily. This concept is well suited and appropriate for the MSW incineration and is being considered in our designing .[38]

7.2 Incinerator design

Incinerator internal sizing requirements

This volume is a function of the total heat released per hour from the burning refuse. The internal volume requirement excludes the ash pit and can be evaluated from below formula :

$$Q_{thr} = \frac{M_b}{Q_{av.}}$$

$$Vi_{min} = \frac{Q_{thr}}{258,750 \text{ W/m}^3}$$

where:

Vimin is minimum theoretical internal volume (m³), Q thr is total heat released (W), Mb is the

mass of refuse burned per hour (kg/h) and Qav is average heating value (kJ/kg). [39]

Preliminary design factors for the MSW incinerators are as follows :

Table – 7.1 – Design factor for incinerator (Source – Incinerator Technology by Alfons Buekens)

	Type of incinerator	
	I	II
Effective grate area per kilogram of refuse per hour(square meter)	0.022	0.04
Ratio of hearth area to grate area	1: 1	1: 1
Effectiveness of hearth area in terms of grate area (percent):		
Firebrick hearths	60	60
C.I.(Cast Iron) grate bars	80	80
Horizontal cross-sectional area of mixing chamber in terms of effective grate area(percent)	25	20
Horizontal cross-sectional area of combustion chamber in terms of effective grate area(percent)	60	30
Cross-sectional area of flue in terms of effective grate area(percent)	25	10
Cross-sectional area of stack in terms of effective grate area(percent)	22	10
Ratio of height of arch above grate to width of furnace not to exceed	1: 1	1: 1

Chamber sizing

Chamber sizing is based on heat release. There is a limit to the quantity of heat that can be released in a particular furnace chamber. Heat release is the amount of heat generated when combustible material burns. The furnace volume must be large enough to allow release of the heat generated by the anticipated waste and the supplemental fuel supported by the law :

$$V = \pi r^2 (L)$$

where:

r is radius of the kiln (m), L is length of the kiln (m) and V is the furnace volume, (m³).

TYPICAL HEAT RELEASE RATE FOR VARIOUS INCINERATOR :

Table – 7.2 – Heat release for incinerator (Source – incinerator technology by Alfons Buekens)

Incinerator type	Heat release (kJ/m ³ -h)
Fluid bed*	350,000-500,000 (bed area)
Multiple chamber	300,000-400,000
Multiple hearth	300,000-400,000
Multiple hearth heat release*	250,000-350,000 (hearth area)
Gaseous waste incinerator	3,000,000-10,000,000
Liquid waste incinerator	1,000,000-3,000,000
Rotary kiln	500,000-1,500,000
Solid waste grate*	150,000-300,000 (grate area)

CALCULATION :

The length of incinerator bed (L) is considered = 11 m .

For daily feeding 600 MT MSW , feeding in incinerator = 600/24=25 MT/ hr .

From available data it is evident that with 25 MT/hr. MSW feeding , for generating 34,950,000 kcal/hr. heat energy , the incinerator bed volume will be maintained 82.5 m³ .

The adiabatic temperature will be maintained 1587 K

Hence the surface area of the incinerator = Volume / Length

$$= (82.5 / 11) \text{ m}^2 .$$

$$= 7.5 \text{ m}^2$$

The ratio of width and height is considered 6:5 (for grate firing incinerator)

Let , width is $6x$, height is $5x$.

Therefore , $30 x^2 = 7.5$

Or , $x = .5$

Hence width of the incinerator is $= (6 \times .5) = 3 \text{ m}$ and height of the incinerator $= (5 \times .5) = 2.5 \text{ m}$.

7.3 Incinerator Retention time :

Retention time means the length of time that the solid materials remain in the primary combustion chamber during incineration. It can be expressed as follows:

$$t = 0.19 \frac{L}{DSN} .$$

t = retention time in minutes.

L = kiln length in metres.

D = kiln diameter in metres.

S = slope of kiln m/m.

N = rotational velocity in rpm.

TABLE FOR STANDARD RETENTION TIME**Table – 7.3 – Retention time data for incinerator (Source – Incinerator Technology by Alfons Buekens)**

Flue gas temperature (°C)	Residence time	
	After burning zone (sec)	Furnace + after burning zone (sec)
950	0.3	1.4
900	1.25	2.35
850	2.15	3.25
800	3.3	4.4

For our incinerator the retention time is considered as 4.4 Second .

Now we summerise the concerned design parameters in a table as below :

Table – 7.4 – Design parameter for incinerator (Source – Incinerator Technology by Alfons Buekens)

INCINERATION DESIGN PARAMETER	VALUES
Initial feed rate	25 ton / hr.
Theoretical Air	44,968.24 m ³
Excess Air	22,454.12 m ³
Adiabatic flame temperature	1,587 K
Heat generated	34,950,000 kcal/hr
Incinerator retention time	4.4 Sec.
Incinerator volume	82.5 m ³
Incinerator bed length	11 metres
Incinerator width	3 metres
Incinerator height	2.5 metres

The partitioning ratio of primary to secondary air is between 80/20 - 40/60 . The task of secondary air is to complete the burnout of the hydrocarbons and carbon monoxide to bring the air –to- fuel to the required level. Furthermore, secondary air can be used as a mixing device for flue gases. Basically, secondary air injection concepts are normal, Tangential configurations; Static mixing device and Rotating cylinder with additional secondary air nozzles, respectively. The grate bars are cooled by the primary combustion air. However, the cooling effect is limited for every high calorific values of the refuse and the bars can be damaged or destroyed by intense heating.

Following figure shows the conceptual design of the municipal solid waste incinerator with its part list.[40]

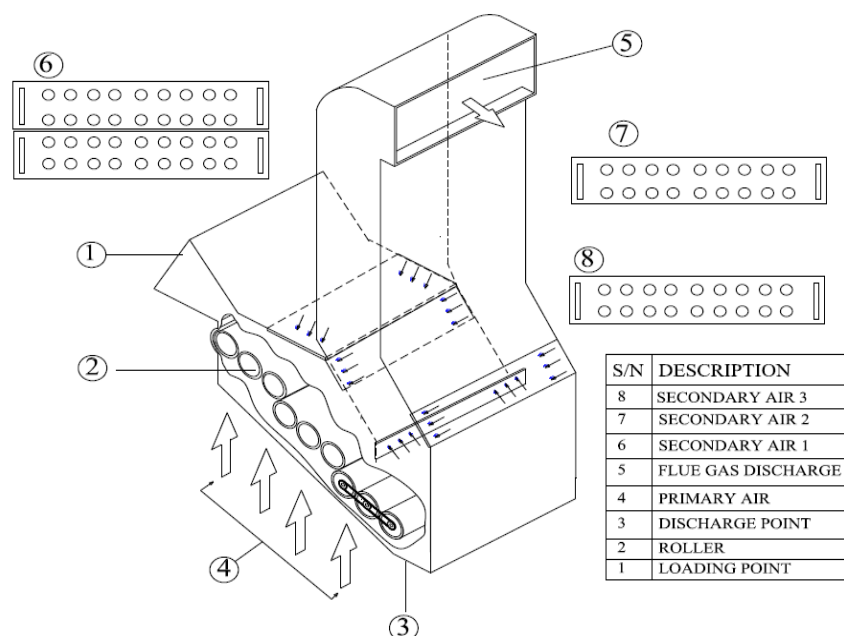


Figure 7.2 – Conceptual design of incinerator (Source – Incineration technology by Alfons Bueken)

8. CONCLUSION & RECOMMENDATION

8.1 CONCLUSION :

This paper evaluated the technical and economic potential for energy recovery from MSW generated from South Dum Dum Municipality , Kolkata .

The following conclusions are noteworthy :

The analysis of the waste generation and composition revealed that the waste was suitable for energy recovery applications. The average calorific value of the waste was calculated to be 1447.5 cal/kg which makes the waste suitable for Waste to energy application . As it had also less moisture content around 32% , it would be regarded suitable for incineration technology in order to recover energy .

The design of the energy recovery facility was based on the use of grate technology in a mass burn facility. It is also the best technology for the type of waste that the landfill receives. The plant was designed for a capacity of 600 tons of waste per day , with one furnace handling 25 tons of waste per hour and a 90 percent availability rate.

The steam properties obtained from the design simulation were sufficient to produce 21 MW of electricity from the MSW of South Dum Dum Municipality .

The mass burn facility allows for the increase in the capacity of the facility without having to stop production of electricity. Increasing on the amount of electricity with time further addresses the energy needs facing the nation.

The thermal treatment of waste needs to be present within the integrated waste management system and plays an important role in it. The basic ability of thermal treatment of reducing mass/volume of wastes is today coupled with the possibility of recovery the valuable energy content of the waste, in part effectively renewable, and in any case produced daily by the local activities. In this sense waste is a domestic energy source widespread on the territory .

During thermal processing of municipal waste its energy is released and recovered in devices called boilers. In order to receive the energy released from the combustion of waste, it is necessary to use boiler systems that enable the transfer of energy to the circulating working medium. The process of energy recovery at modern WTE plants is achieved primarily through the use of steam boilers, i.e. those which use steam-water circuits. Nowadays, municipal waste is combusted mainly in two types of boilers, namely: moving grate boilers and fluidized bed boilers. Moving grate boilers based on inclined reciprocating grates are currently the most widely used type of equipment for municipal waste energy recovery. [41]

Energy recovered from municipal waste, is, without doubt, a very valuable source for the national power grid, much more beneficial from the environment point of view than energy produced from fossil fuels. This article presents the factors which determine the fact that the incineration of municipal waste with the moving grate is widespread among facilities carrying out energy recovery from waste. The grate technology has a wide range of experience and knowledge. Moreover, original and innovative solutions aimed at improving are still being developed. In order to reach the desired benefits from the thermal treatment of municipal waste like significant energy recovery and low environmental impact, an incinerator must be based on the properly selected and optimized boiler. Projects of modern boilers in waste incinerators are taking into account

very wide criteria related not only to potential energy efficiency, but above all the impact of incineration on the environment.

8.2 RECOMMENDATION :

The following recommendation can be made from the present study :

Practice of segregation of MSW (organic, non recyclable inorganic and recyclable inorganic) at the source of generation need to be introduced .

Moisture content of the collected municipal solid waste will be analysed first.

If the moisture content of the MSW is less than 50% , the waste can be used for incineration . If the moisture content of the MSW is more than 50% , the MSW will not be used in incineration for energy harvesting because that will consume much power than generation .

Incinerators are not generally recommended for controlling gases containing halogen- or sulfur-containing compounds, because of the formation of hydrogen chloride, hydrogen fluoride gas, sulfur dioxide, and other highly corrosive acid gases. It may be necessary to install a post-oxidation acid gas treatment system in such cases, depending on the outlet concentration.

Incineration is highly recommended for reducing volume of MSW by up to 90% which means less waste ends up in landfills , reducing the need of more land fill .

8.3 FUTURE SCOPE :

- Nowadays, the yield of municipal solid waste (MSW) is enormous and the growth rate is high. It has been estimated that the quantities of MSW may markedly increase to 2200 million tonnes per year by 2025 because of the rapid urbanization progress and economic growth. Incineration is a promising alternative approach to landfill as a treatment method for the huge number of MSW. It does not only reduce the volume and weight of solid waste by 90% and 70% respectively but also generate energy and heat that could be used for other purposes. On average, over 10% of the generated MSW globally are incinerated at present .
- Focusing on the great potential of municipal solid waste incineration (MSWI) residues in the construction sector, the applications of recycling MSWI residues in construction materials are discussed in this review. Incineration is a promising method for managing the great quantity of municipal solid waste (MSW). Careful handling of incineration residues including fly ash, air pollution control (APC) residues, and bottom ash is required for this approach. The yield of these residues is large, and they contain many toxic and harmful substances. On the other hand, these residues contain valuable components such as SiO_2 , CaO , Al_2O_3 , MgO , which are important components of building materials. Therefore, MSWI residues present huge opportunities for potential recycling and reuse in the construction and building industry.
- The biggest concern of incineration, however, is the vast number of residues generated from the process, including fly ash, air pollution control (APC) residues and bottom ash. Studies have found that the incineration of per ton MSW produces 250–300 kg of bottom ash and 25–30 kg of APC residues and fly ash.¹⁰ These residues are poisonous and harmful because of containing heavy

metals, salts and organic pollutants such as dioxins,¹¹ therefore treatment and disposal methods are needed for safe handling and management. Two basic ways of handling MSWI residues are recycling after appropriate treatment and landfilling. These residues contain SiO_2 , CaO , Al_2O_3 , MgO , *etc.* valuable composites, therefore many researchers have explored the recycling and reuse of them in different fields. In general, these applications can be summarized into four fields, including construction materials, geotechnical applications, agriculture and other application ways. MSWI residues often contain elements of Si, Ca, Al and Fe, like the building materials composition. They are therefore considered to be an alternative raw material for producing building materials,³ such as glass-ceramic,¹⁵ cement,¹⁶ concrete, *etc.* 50 percent of MSWI bottom ashes mixed with metakaolin were used to prepare mixed alkali-activated binders successfully. Alkali-activated MSWI fly ash was used blending with 10% metakaolin to manufacture cementitious material. MSWI fly ash and bottom ash were used as substitutes for Portland cement to prepare concrete for 3D printing. Rotary kiln sintering and non-sintering methods were used to prepare ceramists with MSWI fly ash. The second way of using MSWI residues is geotechnical engineering such as roads, embankments, *etc.* MSWI residues used in agriculture as soil amendment has also been studied. Moreover, one of the main components of MSWI residues, CaO is a candidate for thermochemical energy storage. MSWI fly ash was a promising thermochemical energy storage material.²⁴ Many other application ways have been studied as well. In short, MSWI residues have wide potential for many purposes, and a large number of studies have investigated specific applications for MSWI residues

Cast stone

Cast stone is a kind of crystalline silicate material that is prepared from four processes named melting, cast moulding, crystallisation and annealing. Natural minerals and solid waste residues are two main categories of raw materials for cast stone production. The components of MSWI residues belong to the SiO_2 – CaO – Al_2O_3 ternary-component phase which is imperative in the compositions of raw materials for cast stone production. Therefore, it can be deduced that MSWI residues have great potential in cast stone production. The composition of MSWI residues was analysed first, then the appropriate additives (such as SiO_2 , CaO , Al_2O_3 , *etc.*) were selected to mix with it. The mixture was melted at high temperature, cast in the mould, and then subjected to heat treatment named crystallization and annealing. At last, the cast stone products were obtained.

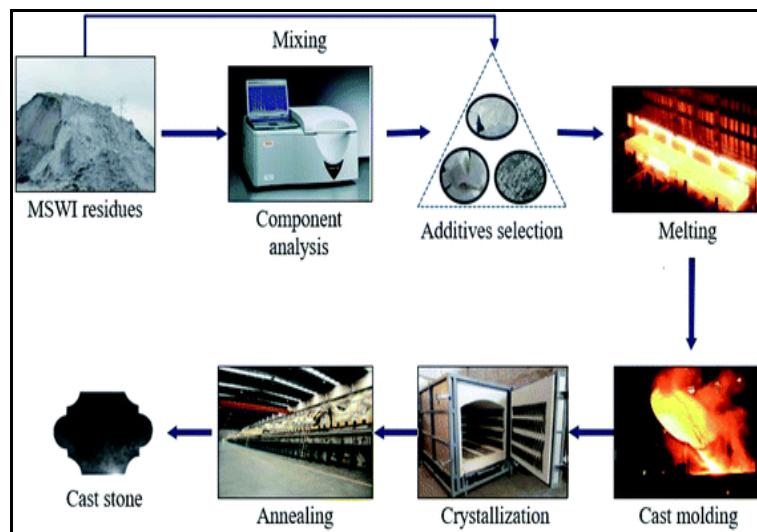


Figure 8.1 – Cast stone (Source – Properties of concrete by A.M. Neville)

Glass-ceramic

Glass-ceramic has excellent mechanical performance and outstanding stabilization efficiency of heavy metals therefore has a good application prospect. MSWI residues contain CaO , SiO_2 , Al_2O_3 , MgO etc., which are consistent with the raw materials composition needed for the glass-ceramic production, therefore, MSWI residues can be used as the raw materials to produce glass-ceramic. SiO_2 and CaO are glass network former and modifier. Therefore, MSWI residues have great potential for recycling and being utilized in glass-ceramic production. The process of preparing glass-ceramic from MSWI residues by sintering method. The suitable batched MSWI residues were melted and quenched and then moulded. The glass-ceramic had excellent properties and was proved to be an environmentally safe product. Sintered glass-ceramic material was prepared from vitrified iron-rich MSWI bottom ash powder. When sintering temperature was increased to $1120\text{--}1130\text{ }^\circ\text{C}$, the glass-ceramic material with zero water absorption, low closed cell percentage and high crystallinity was produced

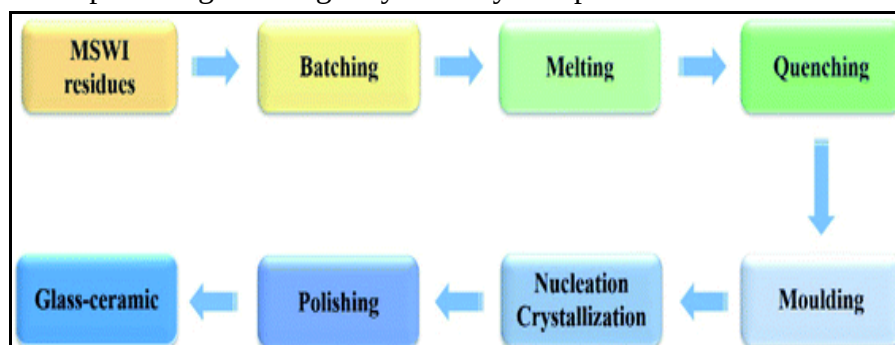


Figure 8.2 – Glass ceramic (Source – Properties of concrete by A.M. Neville)

Cement

Cement is a building material widely used all over the world. However, cement manufacturing industry is energy-intensive and emits a considerable amount of CO₂ and other greenhouse gases, which is considered to be a challenge to cement industry. It is estimated that 850 000 kcal of energy and 1.7 tons of natural raw materials were consumed as well as 0.85 tons of CO₂ released approximately for the production of one ton of cement clinker. The clinker is mixed with MSWI residues, gypsum and other raw materials and then put into the cement mill to grind into fine powder. After that the cement can be obtained.

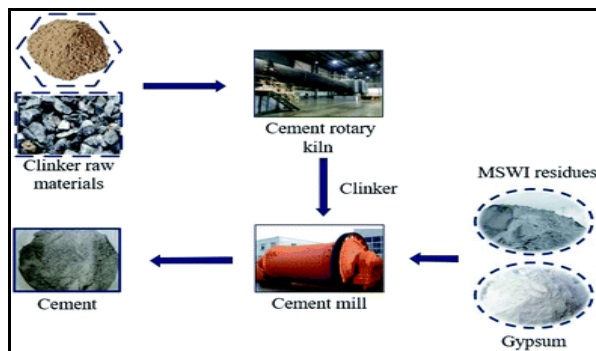


Figure 8.3 – Cement formation (Source – Properties of concrete by A.M. Neville)

Concrete

Concrete is also a kind of widely used building material all around the world. The most common components of concrete include cement, water and aggregates which consist of fine and coarse natural aggregates and sometimes chemical and mineral admixtures. MSWI residues are also competitive materials that can be used in concrete. Figure shows the process of MSWI residues recycled for concrete production. MSWI residues serve as cement or aggregate partial substitute materials. Cement, natural aggregate, other additives and water are added and mixed. The mixture is fully stirred, and then concrete products can be obtained.

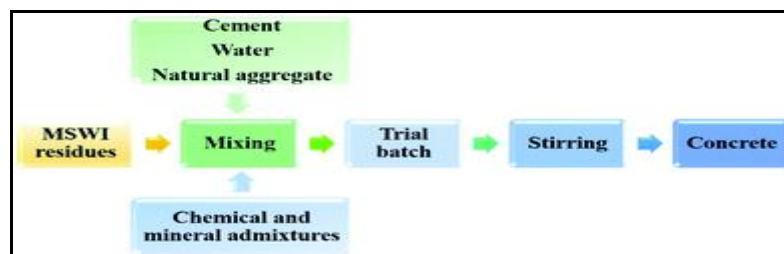


Figure 8.4–Concrete formation (Source – properties of concrete by A.M. Neville)

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10. APPENDIX

APPENDIX 1

Definitions :

Anaerobic Digestion (A.D.): It means controlled process involving microbsal decomposition of organic matter in absence of free oxygen

Biodegradable substance: It means a substance that can be degraded by microorganisms. Biomethanation: It means a process which entails enzymatic decomposition of the organic matter by microbial action to produce methane rich biogas

Collection: It means lifting and removal of solid waste from collection point or any other location.

Composting: It means controlled process involving microbial decomposition of organic matter in presence of oxygen.

Disposal: It means final dumping of municipal solid wastes in terms of specified measures to prevent contamination of ground water, surface water and ambient air quality.

Incineration : It is a form of waste disposal in which waste is burnt. Incineration converts the waste into ash, flue gas, and heat. The heat can be used to generate electricity with a steam turbine.

Leachate: It means liquid that seeps through solid wastes or other medium and has extracts of dissolved or suspended materials from it.

Processing: it means the process by which solid wastes are transformed into new or recycled products.

Recycling: It means the process of transforming segregated solid wastes into raw materials for producing new products, which may or may not be similar to the original products.

Segregation: It means to separate the municipal solid wastes into groups of organic, inorganic, recyclables and hazardous wastes.

Storage: It means the temporary containment of municipal solid wastes in a manner so as to prevent littering, attraction to vectors, stray animals and excessive foul odour.

Transportation: It means conveyance of municipal solid wastes from place to place hygienically through specially designed.

Vermicomposting: It is a process of using earthworms for conversion of biodegradable wastes into compost.

APPENDIX II

List Of Abbreviations

AD: Anaerobic Digestion

AFPRO: ACTION FOR FOOD PRODUCTION

APHA: American Public Health Association

ARTI: Appropriate Rural Technology of India

C/N: Carbon Nitrogen Ratio

CDM: Clean Development Mechanism

COD: Chemical Oxygen Demand

CPCB: Central Pollution Control Board

CPHEEO: Central Public Health and Environmental Engineering Organisation

ECR: Environment Conservation Rule

GHG: Green House Gas

KMC: Kolkata Municipal Corporation

MNRE: Ministry of New and Renewable Energy **MO:** Micro Organisms

MOUD: Ministry of Urban Development.

MSW: Municipal Solid Waste

MT: Metric Ton

NEERI: National Engineering and Environmental Research Institute

PPP: Public Private Partnership

SS: Suspended Solids

SWM: Solid Waste Management

TERI: The Energy and Resources Institute

TS: Total Solid

ULBs: Urban Local Bodies

VS: Volatile Solid

VSS: Volatile Suspended Solids

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