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1.0 Introduction

Waste is generally a highly heterogeneous material, consisting organic substances, minerals, metals and water. Energy from waste is the process of generating energy for electricity and/or heat from treating waste. There are number of new and emerging technologies are able to produce energy and other fuels from waste without direct combustion. Many of these technologies have the potential to produce more electric power from the same amount of fuel. Energy production from waste can be categorized in two ways:

- 1) Thermal technologies
- 2) Non-thermal technologies.

1) Thermal Technologies (TT)

(TT) are processes that create energy in the form of electricity, fuel, or heat from thermo chemical processes of municipal solid waste. The thermal treatment of solid waste is only one part of an integrated waste management system and plays a number of important roles in an integrated waste management system. Thermal treatment covers a range of technologies that extract energy from the waste while reducing its volume and rendering the remaining fraction mostly inert. Thermal treatment can:

- Reduce the volume of waste preserving landfill space
- Allow for the recovery of energy from the solid waste stream
- Allow for the recovery of minerals and chemicals from the solid waste stream which can be reused or recycled
- Destroy a number of contaminants that may be present in the waste stream
- Reduce the need for the long hauling of waste

These technologies can be generally grouped into two main categories: conventional combustion and advanced thermal treatment.

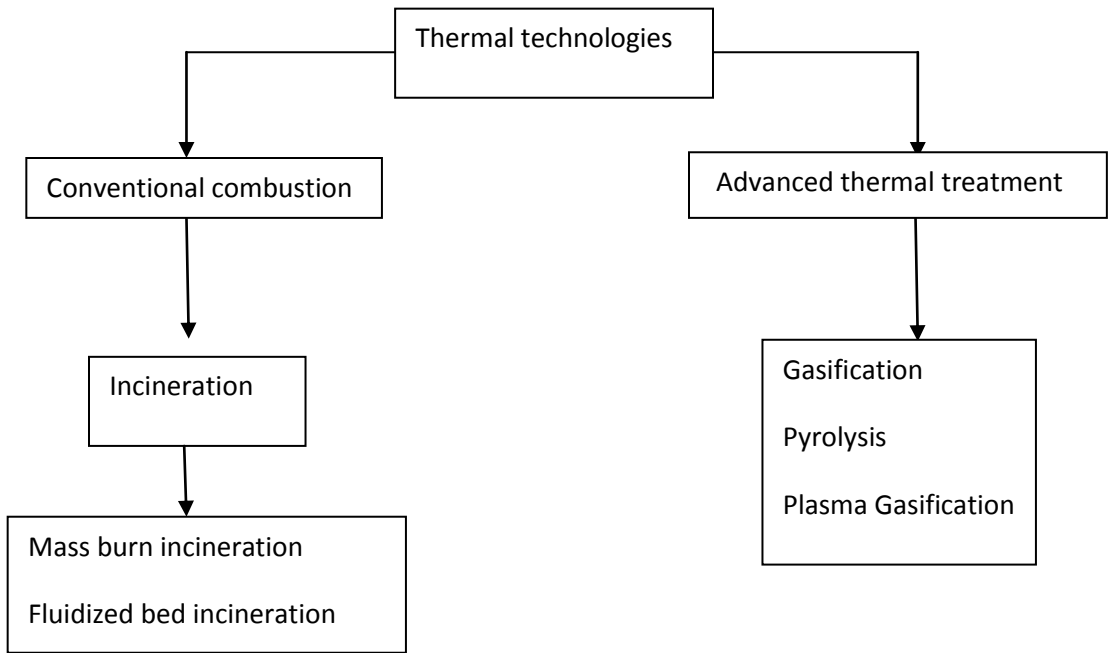


Figure 1.1 Flowchart of the thermal technologies

2) Non-thermal technologies

2.1 Anaerobic digestion (Biogas rich in methane)

2.2 Fermentation production (examples are ethanol, lactic acid, hydrogen)

2.3 Mechanical biological treatment (MBT)

2.3.1 MBT + Anaerobic digestion

2.3.2 MBT to Refuse derived fuel

1 Thermal technologies

1.1 Conventional combustion

1.1.1 Incineration – Mass Burn Incineration

Incineration is used as a treatment for a very wide range of wastes. It is a relatively old method of energy production that involves the combustion of organic substances contained in waste materials and describes as one of the thermal treatment process. It is a controlled process by which solid, liquid, or gaseous combustible wastes are burned and changed into gases, and the residue produced contains little or no combustible materials. It can reduce the volume of MSW by 90% and its weight by 75%. During incineration, the organic fuels substances in the waste will burn when they have reached the necessary ignition temperature and flue-gases are created that contain fuel energy as heat. It produces a combustible fuel such as methane, methanol, ethanol or synthetic fuels. Incineration comes with a number of benefits in specific areas like medical wastes and other life risking waste. In this process, toxins are destroyed when waste is treated with high temperature. The incineration sector has undergone rapid technological development over the last 10 to 15 years.

For incineration process following waste can be directly used for the thermal treatment.

- Municipal wastes (residual wastes - not pretreated)
- Pretreated municipal wastes (selected fractions)
- Non-hazardous industrial wastes and packaging
- Hazardous wastes
- Sewage sludge
- Clinical wastes.
-

Many incineration plants accept several of these types of waste. Waste itself is commonly classified different ways by its:

- Origin (household, commercial, industrial, etc.)
- Nature (hazardous)
- Management methods (separately collected, recovered material)

(a) System operation

Many variables that affect incinerator operation are controlled by operators, so the combustion conditions that control emission rates may be substantially affected by operator decisions. Poor operator controls either of the furnace (by permitting temperature or oxygen concentration to decrease) or of the stoking operation cause to reduce combustion efficiency. In most incinerators, mixing and charging of waste into the incinerator, grate speed, over-fire and under-fire air-injection rates, and selection of the temperature set point for the auxiliary burner are entirely or partially controlled by plant personnel.

In addition, the extent of emission control achieved by post-combustion air pollution control devices (APCD)s depends on how the devices are operated. Operators must be attentive to the flow rate of waste into the incinerator and furnace operation so as to allow for effective function of APCDs. Although some of the most-modern incineration equipment has been automated, there will always be a need for operators to deal with unexpected situations.

(b) Monitoring and Data Collection

For the most recently completed waste incinerators, environmental regulations have led to extensive monitoring of key incineration process conditions, including waste feed rates; feed rates of ash, chlorine, and toxic metals (determined by sampling and analysis of the waste stream); combustion temperatures; gas velocity (or gas residence time), stack-gas concentrations of O₂, CO, total hydrocarbons, HCl, NO_x, and SO_x. Computerized systems collect and record process data, automatically control such process conditions as combustion temperature (by varying fuel feed and air flow rates), and cut off waste feeds etc.

(c) Process Emissions

The principal products of combustion are CO₂, water vapor, and ash, which are respectively oxidation-reaction products of carbon, and hydrogen, and non-combustible materials in the fuel. However, when the combustion reactions do not proceed to their fullest extent, harmful product can be produced. The types and concentrations of contaminants in the waste stream (flue gas) depend on the process type, the waste being burned, and combustion conditions. Such pollutants derive from combustion process or their precursors present in the waste feed or reformation reactions in the gas cooling or APCD.

The products primary concern owing to their potential effects on human health and the environment, are compounds that contain sulfur, nitrogen, halogens (such as chlorine), and toxic metals. Specific compounds of concern include CO, NO_x, SO_x, HCl, cadmium, lead, mercury, chromium, arsenic, beryllium, dioxins and furans, PCBs, and polycyclic aromatic hydrocarbons.

1.1.1.2 Basic linear structure of a waste incineration plant

Following operations are included in modern incineration plant. Each of these stages is generally adapted in terms of design, for the types of waste that are treated at the installation.

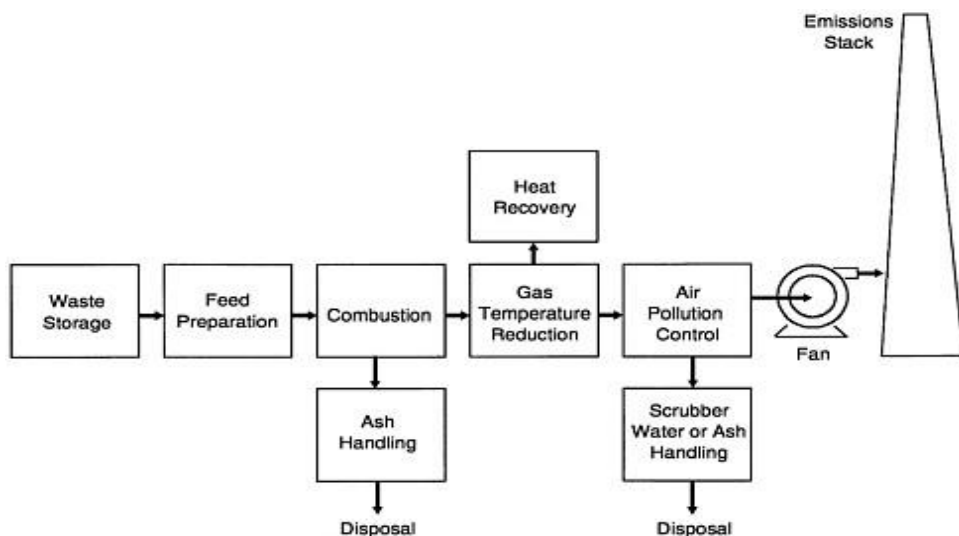


Figure 1.1.2. Linear Structure of the Incineration Plant

Waste incineration facility includes the following operations.

- Waste storage, feed preparation, and feeding practices.
- Combustion in a furnace, producing hot gases and a bottom ash residue for disposal.
- Gas temperature reduction, involving heat recovery via steam generation.
- Treatment of the cooled gas to remove air pollutants, and disposal of residuals from this treatment process.
- Dispersion of the treated gas to the atmosphere through an induced-draft fan and stack.

(a) Waste storage and feed preparation

The different types of wastes that are incinerated may need different types of pretreatment, storage and handling operations. Local collection and pretreatment applied to MSW can influence the nature of the material that received to the incineration plant. The requirements concerning the pretreatment and other operations should be consistent with the collection system in place. Some fractions (glass, metals etc.) can be removed through recycling process approximately. The common waste storage, waste staging, feed preparation and feeding practices for municipal solid-waste, hazardous-waste, and medical-waste incinerators are listed in Table 1. Incoming waste storage and handling processes has been done before process the incinerator. The waste is discharged from the storage into the feeding chute by an overhead crane, and then fed into the grate system by a hydraulic ramp or another conveying system. The grate moves the waste through the various zones of the combustion chamber. The filling hopper is used as a continuous waste supplier. It is filled in batches by the overhead crane. This part of the plant is the highest potential source of fugitive dust and vapor emissions to the environment.

Table 1 Waste Storage and Feeding Practices in Incinerating Process

Waste type	Waste storage	Waste preparation	Feeding to incinerator
Municipal solid waste	Pit	Remove large size and noncombustible waste and special waste like batteries	Crane
	Tipping floor in pile		
Hazardous waste	Bin or drums	Screening for debris removal	Drop chute with double gate airlock Or ram feeder
		Shredding	
Medical waste	Red bag or puncture resistant boxes	-	Manual or ram feeder

(b) Combustion Processes

Combustion is a rapid, exothermic reaction between a fuel and oxygen (O_2). In incineration, the fuel is the waste and the oxygen source is the air. Combustion produces many of the same stable end products. The flame zone of a well designed incinerator is sufficiently hot to break down all organic and many inorganic molecules, allowing reactions between most volatile components of the waste and the oxygen and nitrogen (N_2) in air.

The predominant reactions in the combustion zone are listed in Table 2.

Table 2. Main Chemical Reaction in the Combustion Unit in Incinerator

Reactant in the fed waste	Oxidant	Product
Carbon (C)	Oxygen (O_2)	Carbon dioxide (CO_2)
Hydrogen (H_2)	Oxygen (O_2)	Water vapor (H_2O)
Organic compound	Oxygen (O_2) (incomplete combustion)	Carbon monoxide (CO) & Carbon containing particles
Sulfur compounds	Oxygen (O_2)	Sulfur oxides (SO_x)
Nitrogen compounds	Oxygen (O_2)	Nitrogen oxides (NO_x)
Metal compounds	Oxygen (O_2)	Metal oxides
Hydrogen (H_2)	Organically bound chlorine	Hydrogen chloride (HCl)

The furnace is designed to produce good mixing of the combustion air and the gases and vapors coming from the burning waste. When the combustion is not complete (near the walls of the furnace), combustible components of organic compounds are burned off and leave as fly ash entrained in the flue gas. The incombustible portion of the waste is left behind as bottom ash.

Incineration processes incorporate a number of general methods for ensuring proper combustion and reducing emissions. Inefficient combustion can result in higher levels of products of incomplete combustion. It increases emissions to environment. Therefore optimal design and operation of a furnace is necessary and require giving attention to incineration temperature, turbulence of the gas mixture being combusted, and gas-residence time at the incineration temperature. To achieve an efficient combustion, every part of the gas stream must reach an adequately high temperature for a sufficient period of time, and there must be adequate mixture of fuel and oxygen.

Proper operation is indicated when there is sufficient oxygen present in the furnace, and the gases are highly mixed. A number of new design features and operating techniques have been adopted to increase temperature, extend residence time, and increase turbulence in waste incinerators in order to improve combustion efficiency and provide other benefits like improved ash quality. They include high-efficiency burner systems, waste-pretreatment practices such as shredding and blending, and oxygen enrichment features. Considerable attention has also been given to measurement and control of key process operating conditions to allow better control of the whole combustion process.

(c) Incineration chamber and boiler

Combustion takes place above the grate in the incineration chamber (Figure 1.3).

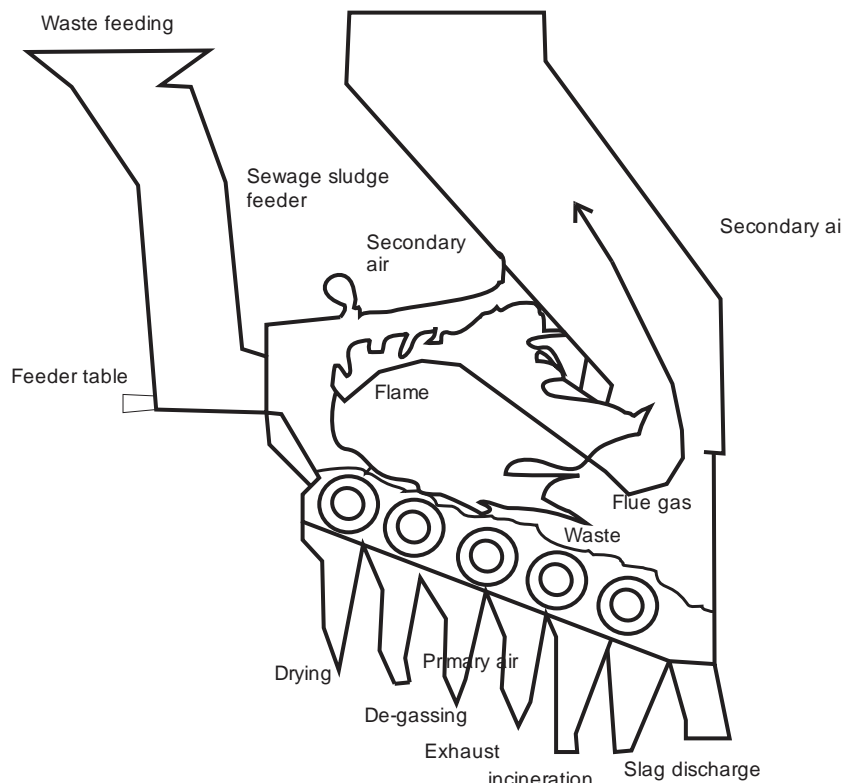


Figure 1.1.3 Main Parts of the Incinerator Chamber

Incineration chamber consists of a grate situated at the bottom, cooled and non-cooled walls on the furnace sides, and a ceiling or boiler surface heater

at the top. As municipal waste generally has a high volatile content, the volatile gases are driven off and only a small part of the actual incineration takes place on or near the grate. The following requirements influence the design of the incineration chamber:

- grate type and size - the size of the grate determines the size of the cross-section of the incineration chamber
- homogeneity of flue-gas flow - complete mixing of the flue-gases is essential for good flue-gas incineration
- sufficient residence time for the flue-gases in the hot furnace - sufficient reaction time at high temperatures must be assured for complete incineration
- partial cooling of flue-gases - flue gas temperature must not exceed an upper limit at the incineration chamber exit.

The detailed design of a combustion chamber is usually linked to the grate type. In general, three different designs can be distinguished. The classification comes from the flow direction of the flue-gases in relation to the waste flow; unidirectional current; countercurrent and medium current (see Figure 4).

(i) Unidirectional current furnace (co-current/parallel flow)

In an unidirectional combustion arrangement, primary combustion air and waste are guided in a co-current flow through the combustion chamber. The flue-gas outlet is located at the end of the grate and low amount of energy is exchanged between the combustion gases and the waste on the grate. The advantage of unidirectional current concepts is the flue-gas has the longest residence time in the ignition area passing through the maximum temperature.

(ii) Counter-flow or countercurrent furnace

Here the primary combustion air and waste are guided in a countercurrent flow arrangement through the combustion chamber and the flue-gas outlet is located at the front end of the grate. The hot flue-gases facilitate drying and ignition of the waste. Counterflow current concepts require higher secondary or upper air additions.

(iii) Medium-current or centre-flow furnace

In this case, the flue-gas outlet is located in the middle of the grate. The composition of municipal solid waste varies considerably and the medium current concept is a compromise for a wide feed value spectrum. A good mixture of all partial flue-gas currents may occur through mixing well with secondary air.

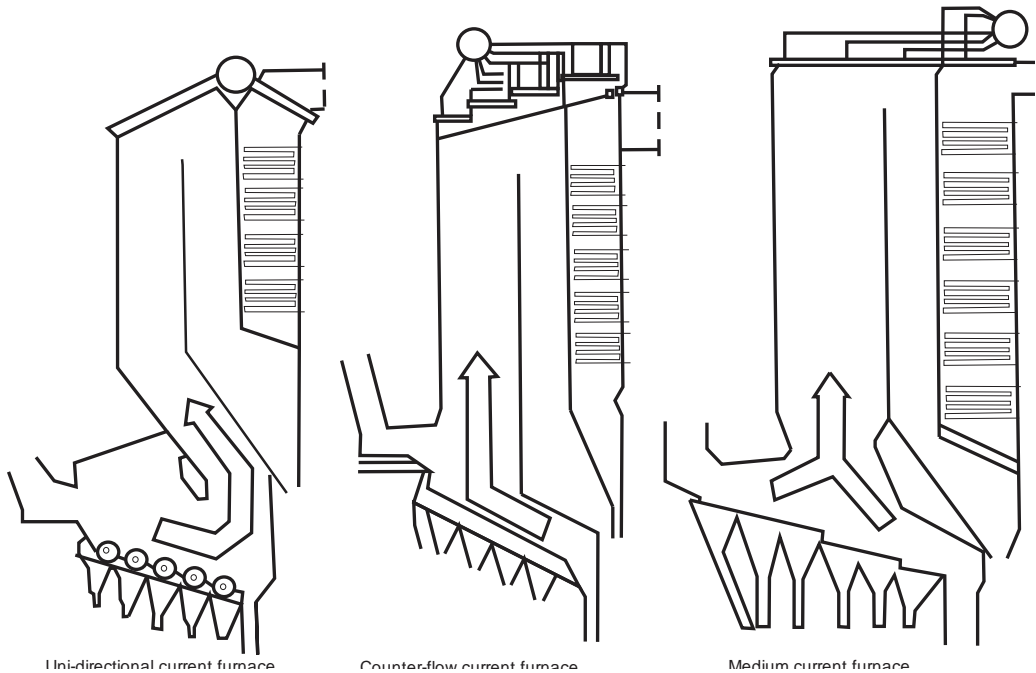


Figure 1.1.4. Different Design of the Combustion Chambers with Grate Type

(d) Incinerators and their types:

There are several types of plants for burning waste. Municipal solid waste can be incinerated in several combustion systems including travelling grate, rotary kilns, and fluidised beds. Fluidised bed technology requires MSW to be of a certain particle size range.

(i) Moving Grate Incinerator (MGI)

Moving grate incinerators are referred to as Municipal Solid Waste Incinerators. It can accommodate large quantities and variations of MSW

composition and calorific value. There is no pretreatment of the MSW before it is combusted using a moving grate. Moving-grate incineration requires that the grate be able to move the waste from the combustion chamber to allow for an effective and complete combustion. The waste is first dried on the grate and then burnt at a high temperature (850 to 950°C) accompanied with a supply of air. Air flows through the waste, cooling the grate. Air gets blown through the boiler to complete the burning of the flue gases to improve the mixing and excess of oxygen. The hot combustion gases are commonly used in boilers to create steam that can be utilized for electricity production.

A single incineration plant is able to process thirty-five metric tons of waste per hour of treatment. Compared to other thermal treatment technologies, the unit capacity and plant capacity of the moving grate incineration system is the highest, ranging from 10 to 920 tpd (ton per day) and 20 to 4,300 tpd. It is the only treatment type which has been proven to be capable of treating over 3,000 tpd of mixed MSW without requiring any pretreatment steps.

(ii) Rotary-kiln Incinerator

Incineration in a rotary kiln is normally a two stage process. It consists of a kiln and a separate secondary combustion chamber. Solid waste is introduced into the upper end of an inclined, slowly rotating refractory lined steel cylinder. The steps of drying, combusting and ash cooling are accomplished along the length of cylinder as the waste moves through it. Application of rotary kiln incineration to treat mixed MSW has numerous technical problems such as thermal shock, ash melting and deposition and corrosion which require intensive maintenance.

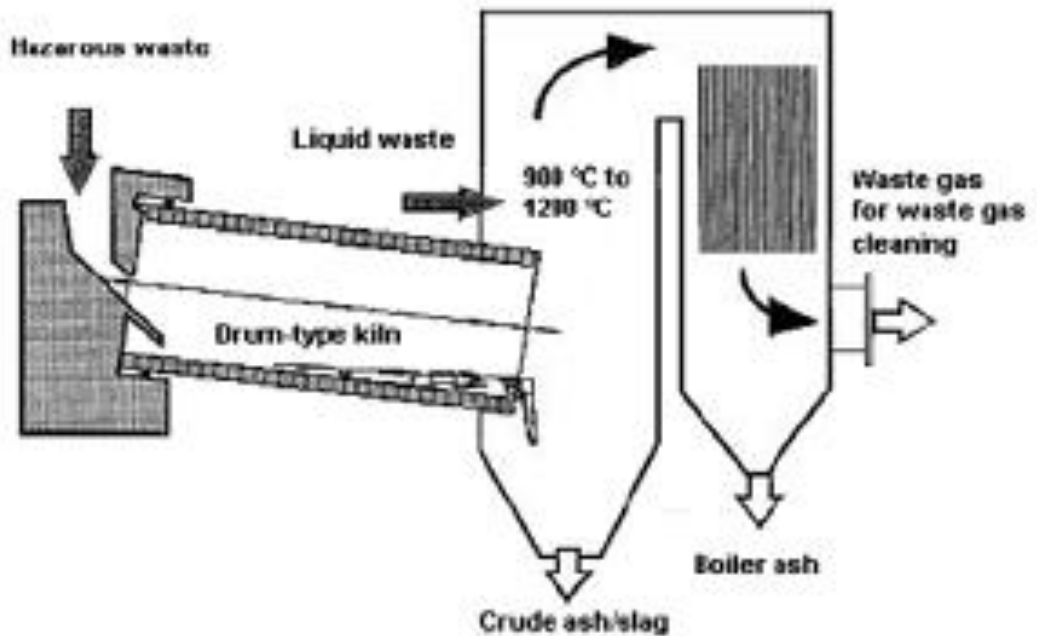


Figure 1.1.5 Rotary Kiln Incinerator

(e) Bottom ash discharger

The bottom ash discharger is used for cooling and removal of the solid residue that accumulates on the grate. Water-filled pressure pistons, drag constructions and belt conveyors are commonly used to extract the bottom ash. The water used for cooling is separated from the grate ash at the exit, and may be re-circulated to the ash discharger.

1.1.1.3 Gas temperatures reduction techniques

Gas cooling techniques are integral to incineration system design, and can be important with respect to emissions of certain pollutants. The most common combustion-gas cooling techniques for incinerators are waste-heat boilers, and direct-contact water-spray quenches. Waste-heat boilers are employed on all new municipal solid waste-to-energy plants, many hazardous-waste incinerators, and some of the larger medical-waste incinerators.

Waste-to-energy plants have radiant water wall furnaces as well as convective boiler sections. Combustion gases are quenched by water sprays atomized into the hot gas flow. Other, less common, gas-temperature

reduction methods include air-to-gas heat exchangers and direct gas tempering with air.

(a) Incineration air feeding

The incineration air fulfils the following objectives:

- provision of oxidant
- cooling
- avoidance of slag formation in the furnace
- mixing of flue-gas.

Air is added at various places in the combustion chamber. It is usually described as primary and secondary, although tertiary air, and re-circulated flue-gases are also used.

The primary air is generally taken from the waste bunker. This lowers the air pressure in the bunker hall and eliminates most odour emissions from the bunker area. Primary air is blown by fans into the areas below the grate, where its distribution can be closely controlled using multiple wind boxes, and distribution valves.

The air can be preheated if the value of the waste degenerates to such a degree that it becomes necessary to pre-dry the waste. The primary air will be forced through the grate layer into the fuel bed. It cools the grate bar and carries oxygen into the incineration bed.

Secondary air is blown into the incineration chamber at high speeds via, for example, injection lances or from internal structures. This is carried out to secure complete incineration and is responsible for the intensive mixing of flue-gases, and prevention of the free passage of unburned gas streams.

(b) Heat recovery

The heat energy in the flue gas is recovered to produce hot water or steam in the Boiler. The steam generated may be saturated or superheated and could be used for process applications or for power generation via a steam turbine. The heat energy remaining in the flue gas after the generation of steam is used to preheat feed water for the boiler in heat exchanger.

(i) Auxiliary burner

At start-up, auxiliary burners are commonly used to heat up the furnace to a specified temperature through which the flue-gases can pass. This is the main use of auxiliary burners. These burners are usually switched on automatically if the temperature falls below the specified value during operation. During shut down, the burners are often only used if there is waste in the furnace.

1.1.1.4 Air Pollution control Devices

1.1.1.4.1 Pollution

Incineration is conducted with a number of outputs, which include ash and flue gas emission. Before the flue gas cleaning systems were introduced, the flue gas has to move to atmosphere with lot of pollutants leading to pollution.

1.1.1.4.2 Solidify Outputs

Flue ash and Bottom ash is produced with the processing of waste materials and settle at the bottom of the incineration plant. The ash, which is produced, is four to five percent of total weight of the waste processed while the flue ash makes up some ten to twenty percent of total weight of waste material. The heavy metals, which are contained in the flue or bottom ash, are lead, cadmium, zinc and copper. A small amount of furans and dioxins are also produced. Flue ash is hazardous while bottom ash is not that dangerous or injurious to health.

1.1.1.4.3 Emission of gases

The most concern issue in MSW's incineration is production of a huge amount of furans and dioxins. These are considered staidly injurious to health. Incinerators are produced a vast amount of Carbon dioxide. Carbon dioxide is considered as a green house gas. Some other emissions of gases by waste processing are sulfur dioxide, hydrochloric acid, fine particles and heavy metals.

In modern incinerator, APCDs are designed to remove two classes of pollutants which are particulate matter and acid gases. But modern municipal solid-waste incinerators are equipped for particulate matter, acid gas, s well as dioxin and mercury. The municipal solid-waste incinerators employ fabric

filters or dry electrostatic precipitators (ESP) for removal of particulate matter. Spray dryer absorbers and dry-lime injection systems are used for acid gas (HCl and SO_x) removal. Dry powdered activated carbon injection systems provide dioxin and furan and mercury removal.

1.1.1.4.4 Removal of Particulate Matter

Particulate matter consists of noncombustible matters which exist in the flue gas, and solid or aerosol form that are the products of incomplete combustion. Particulate matter from waste combustors includes inorganic ash and carbonaceous soot formed in the combustion process. The inorganic-ash fraction of the particulate matter consists of minerals and metallic species. These materials are conserved in the combustion process and leave the combustion chamber as bottom ash or fly ash. Soot is a product of incomplete combustion or unburned carbon in the form of fine particles or deposits on inorganic particles. There are four general methods for controlling particulate emissions from waste combustors.

1. Limit the ash content of the waste feed via source control or selection
2. Design and operate the primary combustion chamber to minimize fly-ash carryover
3. Design and operate the combustion chamber(s) in accordance with good combustion practice to minimize soot formation
4. Use well-designed and well-operated fine-particle APCDs

Source control of ash-producing waste constituents is an obvious method to reduce particulate emission, but it is impractical for most waste combustors. However, some incinerators and boilers burning liquid hazardous waste are able to meet particulate matter emission limits by following these methods. These methods are effective in reducing particle loadings in the combustion gas. But reducing levels are not sufficient to meet current maximum-available-control-technology (MACT) emission standards for particulate matter. Therefore well designed and well operated different categorized particle control devices are used in modern incinerators.

- 1) Filtration collectors –
 - primary fabric filters (baghouses)
 - electrostatic collectors (dry and wet electrostatic precipitators (ESPs))
 - Ionizing wet scrubbers; and wet inertial-impaction collectors

(a) Fabric Filters

Fabric filters are used at relatively low flue-gas temperatures (about 280-400°F). when the flue gas passes through filter bags particles in the gas streams are collected on the filters. Fabric filters are highly efficient and widely used today in municipal solid waste incineration plant. The performance of fabric filters is depending on particle loading, particle size, physical, chemical characteristics of the particles, fabric type, gas flow rate, total surface area and cleaning methods. The fabric type must be matched to the temperature range of the application and the chemical composition of the gas for good performance and bag durability. However, best environmental performance is achieved at lower temperatures (to minimize dioxin and furan production within the APCD itself).

(b) Dry and wet electrostatic precipitators

Dry ESPs are widely used today in municipal solid waste incineration plants and hazardous waste incineration plants. Dry ESPs are less effective than fabric filters for collection of sub micrometer particulate matter (0.1-1.0 μm). Their performance is influenced by a variety of design characteristics and operating conditions, including the number of electric fields used, charged electrode wire (or rod), shape of the grounded collection plate (or cylinder), specific collection area (ratio of collection surface area to gas flow rate), electrode design, operating voltage and current, ignite rate, collector cleaning method, fluctuations in gas flow rate, temperature, particulate-loading, particle-size distribution, and particle resistivity.

Wet ESPs are not widely used and are primarily in hazardous waste incineration plants. Wet ESPs are constructed from materials that resist acid corrosion. Wet scrubbers have been used to control particulate matter for most hazardous-waste and medical-waste incinerators. ESPs are able to meet necessary regulatory requirements in many applications.

1.1.1.4.5 Acid Gases

Acid gases are flue-gas constituents that form acids when they combine with water vapor, condense, or dissolve in water. Acid gases include NO_x , SO_x , HCl, hydrogen bromide, hydrogen fluoride, and hydrogen iodide. HCl and SO_2 are often present in uncontrolled flue-gas streams in various concentrations. Free halogens such as chlorine, bromine, and iodine can also be produced at low concentrations from combustion of wastes that contain compounds of those elements.

There are two sources of NO_x from incineration processes. They are called as thermal NO_x and fuel NO_x . Thermal NO_x is formed by the reaction of nitrogen and oxygen in high temperature in the combustion air. Fuel NO_x is formed by the oxidation of chemically-bound nitrogen in the waste (or fuel). Conversion of bound nitrogen to NO_x is strongly influenced by the existing oxygen concentration and less sensitive to temperature.

A commonly used APCD for removal of acid gases is a packed-bed absorber.

(a) Acid Gas Scrubbers

A scrubbing liquid is trickled through a matrix of structured packing. Gas is simultaneously passed through it contacting gas and liquid over a large surface area. The scrubbing liquid can be water or an alkaline solution, which reacts with the acid-gas constituents. The important operating criteria for wet acid-gas absorbers are gas velocity, liquid/gas ratio, packing mass transfer characteristics.

(b) Spray-dryer scrubbers

They are used in municipal solid-waste and hazardous-waste incinerators for acid-gas control. The spray dryers use slurries of lime, sodium carbonate, or sodium bicarbonate as the alkaline reagent. The water in the atomized slurry droplets evaporates, cooling the gas, and the alkali particles react with the acid-gas constituents to form dry salts. The salts and un-reacted alkali should be captured in a downstream fabric filter or electrostatic precipitator.

(c) Dry-injection scrubbers

They use an alkaline reagent without water, have been used. They are typically not as efficient as spray-dryer absorbers at removing emissions. The important design and operating criteria for spray-dryer absorbers and dry-alkali scrubbers include gas temperature in the reagent contacting zone, reagent type and their distribution with gas.

(d) NO_x Controls

NO_x emissions can be reduced by designing combustion furnace and modifying combustion process. Combustion furnace designs to reduce thermal NO_x. Combustion process modifications can be reduced NO_x formation controlling the amount of oxygen available during the combustion process within a specific temperature range. Lower-oxygen condition above the grates is necessary to reduce NO_x. Within the plant most NO_x create in this higher temperature. To minimize NO_x formation, the furnace should be operated within narrow ranges of temperature and excess oxygen (9-12%). They should be well mixed within the MSW incinerators. NO_x flue gas control systems include selective non-catalytic reduction (SNCR), selective catalytic reduction (SCR), and wet flue gas for denitrification.

SNCR reduces NO_x by injecting ammonia or urea into the furnace via jets positioned at the location where temperatures are about 3230-3630°C. In this temperature range, the injected ammonia or urea combines with nitrogen oxide to form water vapor and elemental nitrogen.

SCR operates at a lower flue gas temperature than SNCR. Ammonia is injected into the flue gases when they are at about 1230°C, and the mixture is passed through a catalyst bed. The catalyst bed may be shaped in a variety of forms (honeycomb plates, parallel ridged plates, rings, tubes, and pellets) while the catalyst can be one of a variety of base metals (copper, iron, chromium, nickel, molybdenum, cobalt, or vanadium). The biggest disadvantage of SCR for incineration applications is reheated the combustion gas to the required 600°F temperature range after cooling below this level to remove particulate matter. The catalyst beds required for SCR must be installed downstream of highly effective particulate removal devices to avoid fouling.

Wet scrubbers for NO_x removal are comparable to wet acid gas absorbers in configuration. They use strong oxidizers in aqueous solution to convert NO to NO₂ (which is water soluble in caustic solution) or NO₃⁻(nitrate), which is water soluble.

1.1.1.4.6 Products of Incomplete Combustion

Organic and inorganic substances are broken down into free radicals in the combustion unit. They combine with oxygen or hydroxyl radicals and sometimes combine among themselves to form many organic compounds. Most of these compounds can be destroyed in the flame zone of a well designed incineration system. Such compounds that are not combusted and released into the exhaust gas are called products of incomplete combustion (PICs). PIC emissions heavily depend on combustion conditions and design and operation of the combustion device. Depending on the temperature, some of the heavy organic constituents can condense onto fine particles (CO, trace organic chemicals (methane, ethane, acetylene, and benzene), dioxins and furans, partially oxidized organic compounds (acids and aldehydes), and polycyclic aromatic hydrocarbons).

Dioxins and furans are the most-hazardous organic PICs found in the flue gas of any combustion device. (polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs)). Numerous factors have been associated with dioxin and furan formation, including the presence of particulate carbon, metal catalysis, combustion efficiency, temperature, and presence of precursors. For poorly designed and poorly operated incinerators, the flue gas dioxin and furan concentrations can be much higher than typical combustion devices. Dioxin and furan emissions can be controlled through good combustion practice and rapid cooling of the combustion gas to air pollution control system temperatures (generally ranging from 285°F to 300°F). Modern incinerators have the facilities to achieve zero discharge of these chemicals.

1.1.2 Fluidized Bed Incinerator

The fluidized bed incinerator consists of a lined combustion chamber loaded with a large granular bed of coarse sand or silica which acts to transfer heat to the waste uniformly. During operation, heated air is blown vertically through the bed at a high flow rate. The bed of particles causes to bubble or boil. Fluidized bed combustion is conducted at relatively low temperature at 760°C to 870°C and the average gas residence time is high (over 5 seconds), resulting in effective combustion even with wet waste. Fluidized bed technology is widely applied to treating sewage sludge. Combustion of

mixed MSW in a fluidized bed incinerator requires preprocessing of the waste. The sand along with the pretreated fuel or waste is kept suspended and is pumped through the air currents into a homogenous refuse derived fuel and its application is limited. In this type of incinerators, air is blown at high speed over a sand bed. The air moves through the bed. This let the volume of the waste, sand and fuel to be circulated throughout the furnace, completely.

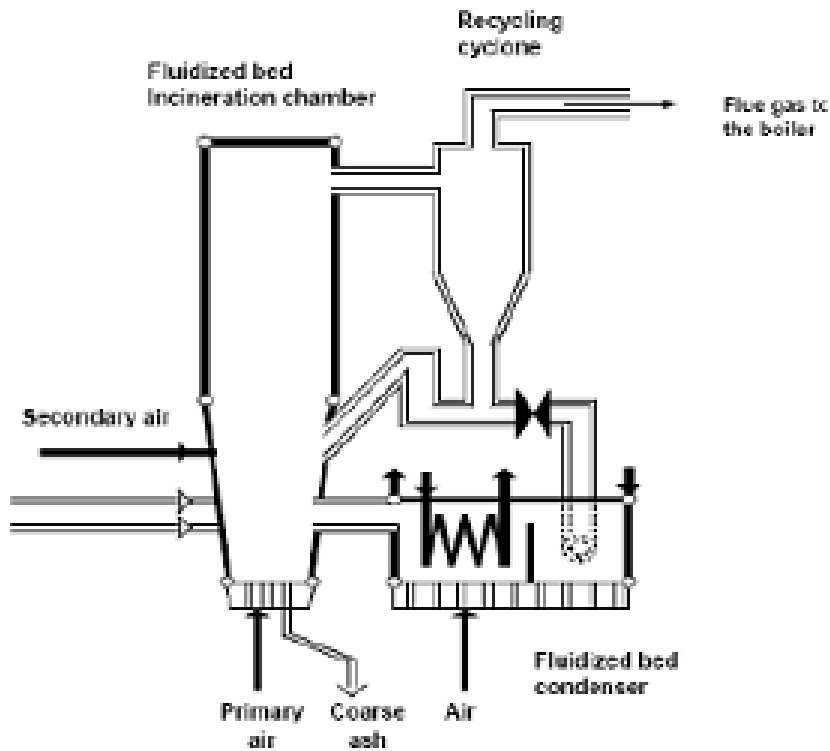


Figure 1.1.6 Fluidized Bed Incinerator

1.2 Advance Treatment

1.2.1 Gassification

1.2.1.1 Introduction

Gasification is a process that converts carbonaceous materials, such as coal, petroleum, or biomass, into carbon monoxide and hydrogen by the reaction of raw materials at high temperatures with a controlled amount of oxygen. This undergoes a series of reactions that produces a gaseous mixture is called synthesis gas or syngas and can be used as fuel. Gasification is a very efficient method for extracting energy from many different types of organic materials, and also has applications as a clean waste disposal technique. However, almost any type of organic material can be used as the raw material for gasification, such as wood, biomass, or even plastic waste. Thus, gasification may be an important technology for renewable energy. This syngas is potentially more efficient than direct combustion of the original fuel. They can be burned in gas engines, used to produce methanol and hydrogen, or converted into synthetic fuel (Figure 1).

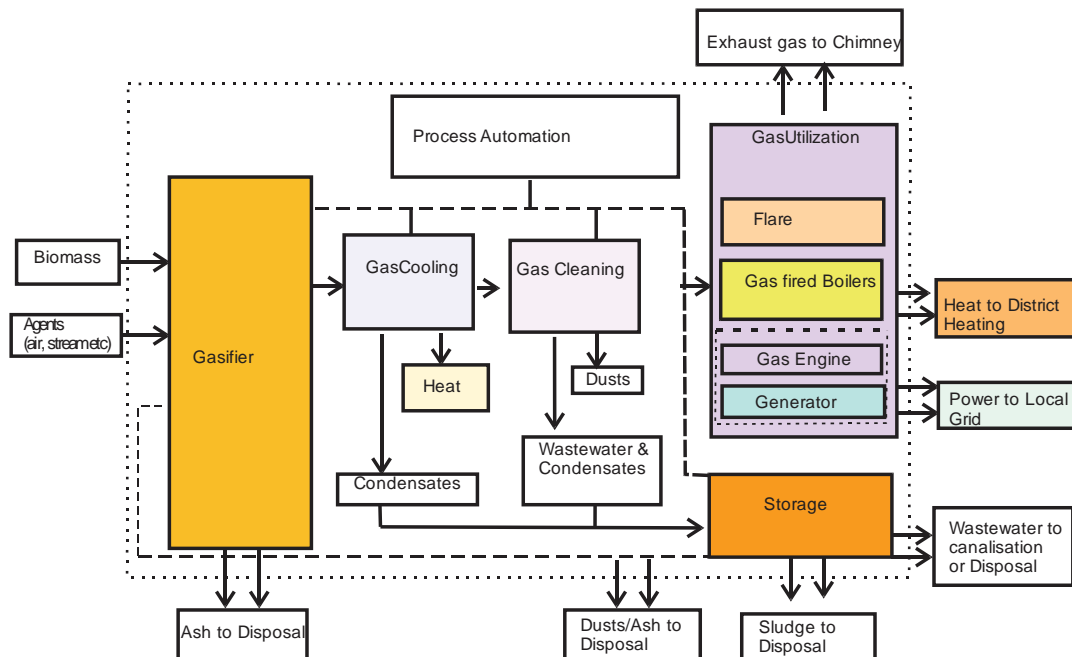


Figure 1.2.1 Main component in the gassifier

There are a large number of different feedstock types for use in a gasifier, each with different characteristics, including size, shape, bulk density, moisture content, energy content, chemical composition, ash fusion characteristics, and homogeneity of all these properties. Coal and petroleum coke are used as primary feedstocks for many large gasification plants worldwide. Additionally, a variety of biomass and waste-derived feedstocks can be gasified, with wood pellets and chips, waste wood, plastics and aluminium, Municipal solid waste (MSW), Refuse-derived fuel (RDF), agricultural and industrial wastes, sewage sludge, switch grass, and crop residues all being used.

1.2.1.2 Basic gasification process

(a) Bunker Section (drying zone)

Solid fuel is introduced into the gasifier at the top. Heat transfer from the lower parts of the gasifier drying the biomass fuel within this zone. The water vapour will flow downwards and part of it may be reduced to hydrogen in the oxidation zone and the rest will end up as moisture in the gas.

(b) Pyrolysis Zone

Pyrolysing of biomass fuel is started at temperatures above 250°C. Through this process large molecules (such as cellulose, hemi-cellulose and lignin) break down into medium size molecules and carbon (char). The pyrolysis products flow downwards into the hotter zones of the gasifier. Some will be burned in the oxidation zone, and the rest will break down to even smaller molecules of hydrogen, methane, carbon monoxide, ethane, ethylene, etc.

(c) Oxidation Zone

A burning (oxidation) zone is formed at the level where oxygen (air) is introduced. Reactions with oxygen are highly exothermic resulting a sharp rise of the temperature up to (1200 – 1500)°C. An important function of the oxidation zone, apart from heat generation, is to convert and oxidize all condensable products from the pyrolysis zone.

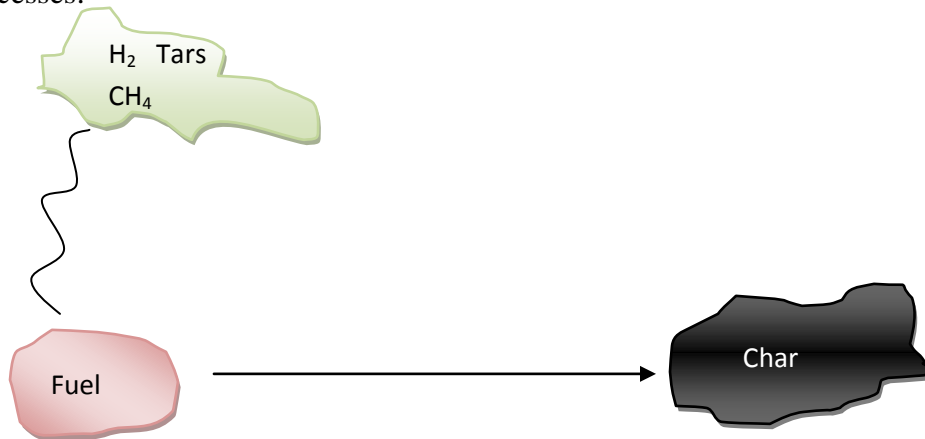
(d) Reduction zone

The reaction products of the oxidation zone (hot gases and glowing charcoal) are moved downward into the reduction zone. In this zone the sensible heat

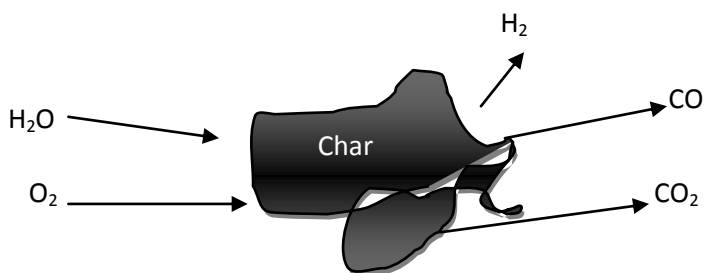
of the gases and charcoal is converted into chemical energy of the producer gas. The end product of the chemical reactions is a combustible gas. It can be used as fuel gas in burners and internal combustion engines after removing dust. The ashes which result from gasification process should occasionally be removed from the gasifier. Usually a moveable grate in the bottom of the equipment is necessary to stir the charcoal bed in the reduction zone to prevent blockages which can lead to obstruction of the gas flow.

1.2.1.3 Chemical reactions

In a gasifier, the carbonaceous material undergoes several different processes:



Pyrolysis of carbonaceous fuels

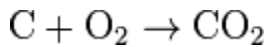


(a) Gasification of char

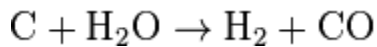
1. The drying process occurs at around 100°C. Typically the resulting steam is mixed into the gas flow and involved chemical reactions.
2. The devolatilization process occurs at around 200-300°C. Volatiles are released and char is produced up to 70% from total weight. The

process is dependent on the properties of the carbonaceous material, the structure and composition of the char.

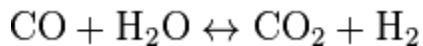
3. The combustion process occurs by reacting volatile products and some of the char with oxygen to form carbon dioxide and small amounts of carbon monoxide, which provides heat for the subsequent gasification reactions.



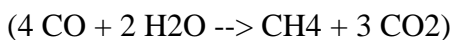
4. The gasification process occurs as the char reacts with steam to produce carbon monoxide and hydrogen, via the reaction



5. In the reversible gas phase, water gas reaction reaches equilibrium very fast at the temperatures in a gasifier. This balances the concentrations of carbon monoxide, steam, carbon dioxide and hydrogen.



Limited amount of oxygen or air is introduced into the reactor to allow burning some of the organic material to produce carbon dioxide and energy and convert to hydrogen and carbon dioxide. Further reactions occur between the formed carbon monoxide and residual water from the organic material to form methane and excess carbon dioxide.



This third reaction occurs more abundantly in reactors between reactive gases and organic materials with existing heat and pressure. Catalysts can be used to improve reaction rate with a fixed residence time.

1.2.1.4 Gasification Types

Several types of gasifiers are currently available for commercial use: counter-current fixed bed, co-current fixed bed, fluidized bed, entrained flow, plasma, and free radical.

(a) Counter-current fixed bed ("up draft") gasifier

It is very simple and old gasifier type. The biomass is fed at the top of the reactor and moves downwards. The air intake is at the bottom and the gas leaves at the top. The biomass moves in counter current to the gas flow, and passes through the drying zone, the distillation zone, the reduction zone and the hearth zone. In the drying zone the biomass is dried. In the distillation or pyrolysis zone the biomass is decomposed in volatile gases and solid char. In the reduction zone many reactions occur involving char, carbon dioxide and water vapour to produce carbon monoxide and hydrogen. In hearth zone the remaining char is combusted providing the heat, the carbon dioxide and water vapour for the reactions involved in the reduction zone. Ashes are removed from the bottom of the gasifier. This type of gasifier has high equipment efficiency and can operate for various type of feedstock. Production of tars and methane is significant at operation temperatures and gas must be cleaned before use. The tar can be recycled for the reactor.

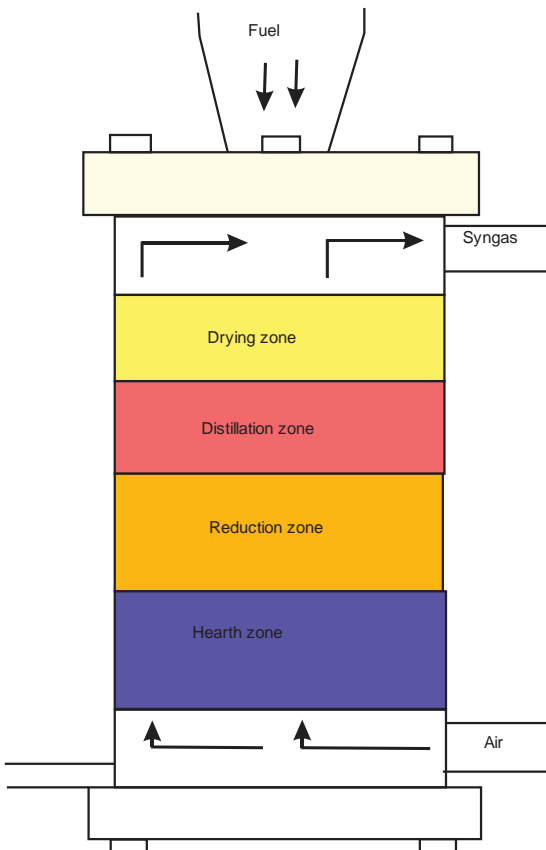


Figure 1. 2. 2 Counter-current fix bed gassifier

(b) Dwindraught or co-current gasifiers

In a down-draught reactor biomass is fed at the top and the air intake is also at the top or from the sides. The gas leaves at the bottom of the reactor and fuel and gas move in the same direction (Figure 3). The same zones can be distinguished as in the up-draught gasifier, although the order is different. These zones are mainly heated by radiation (and partly convection) heat from the hearth zone, where a part of the char is burnt. The pyrolysis gases pass also through this zone to be burnt and the burning is depend on the gasifier design, biomass feedstock and the operator skill. Remaining char and the combustion products carbon dioxide, water vapour pass to the reduction zone and formed CO and H₂. The production of gas through down-draught gasifier is low tan content and suit for engine applications.

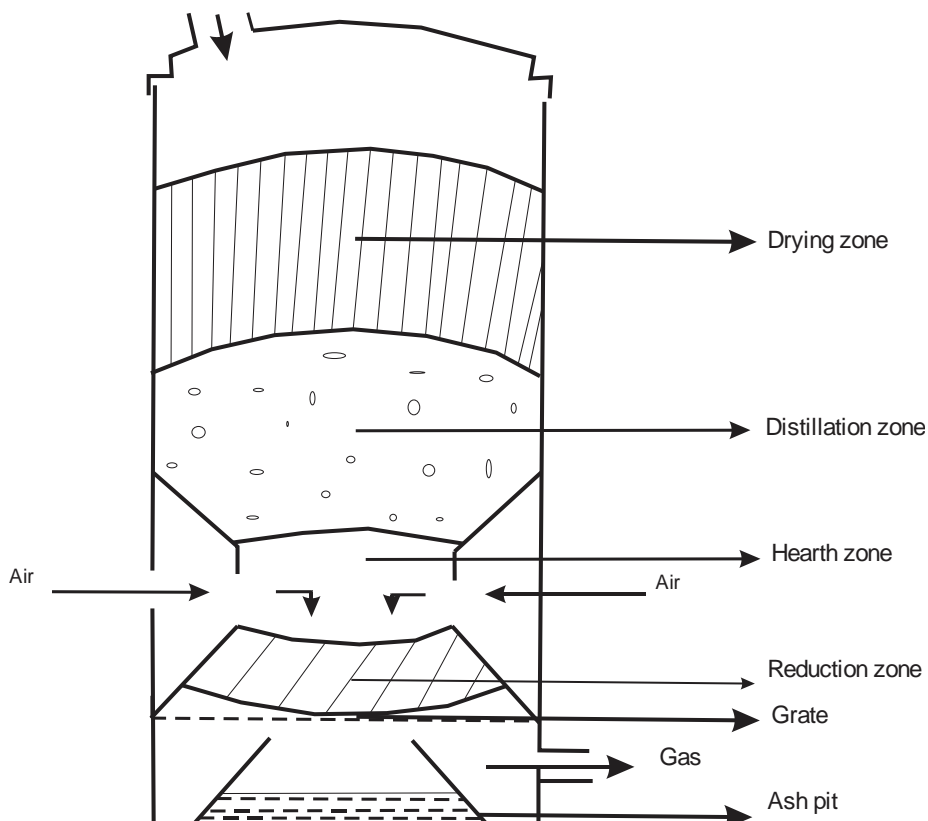


Figure 1.2.3 Co-current gasifier

(c) Cross-draught gasifier

Cross-draught gasifiers are used charcoal. Therefore produced charcoal should be in high quality. Charcoal gasification is occurred in very high temperatures (1500°C and higher) in the hearth zone. Gas cleaning techniques such as gas filters, cyclones have to be applied.

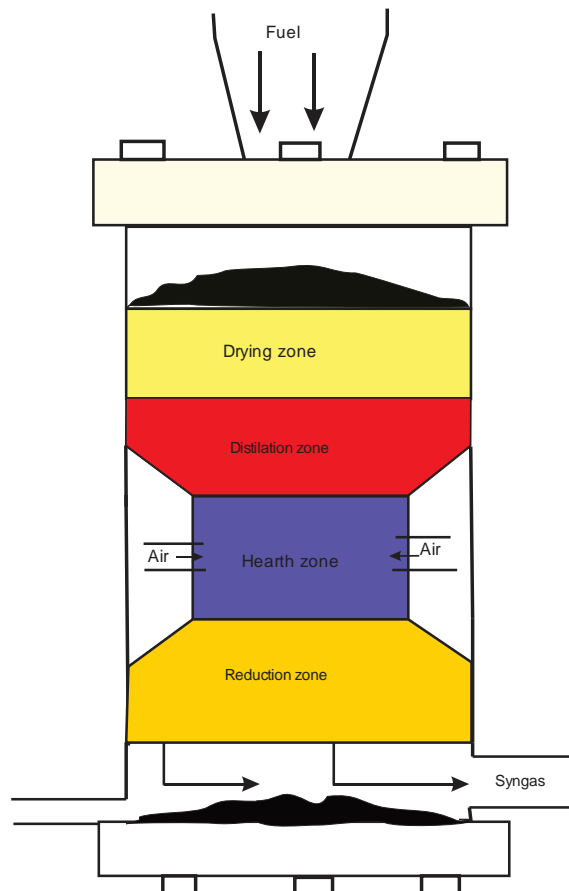


Figure 1.2.4 Cross draught gassifier

(d) Open core gasifier

Open core gasifiers (figure 4) are especially designed to gasify fine materials with low bulk density (for example rice husks). Special devices, like rotating grates, may be included to stir the fuel and to remove the ash. They produce high ash amount. The bottom of the gasifier is set in a basin of water to remove ash.

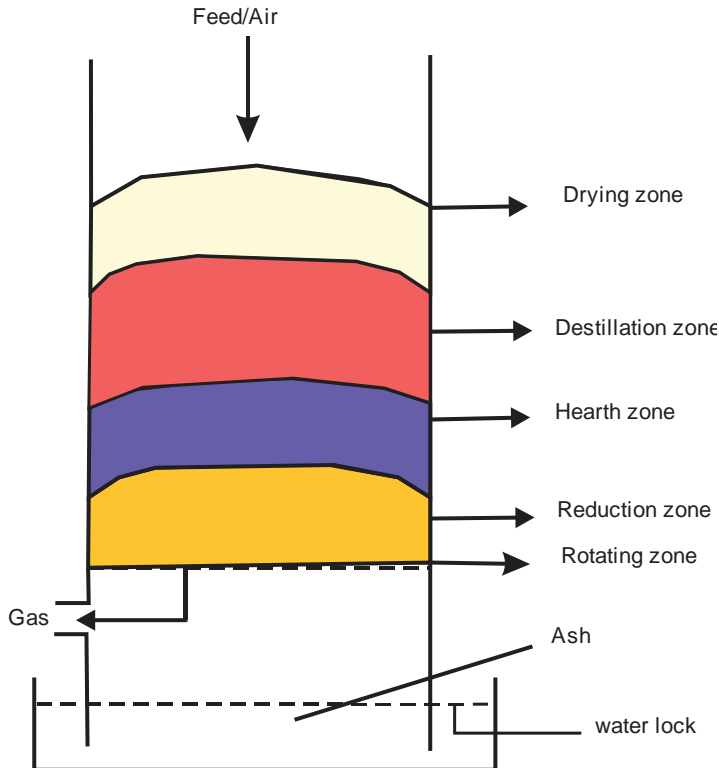


Figure 1.2.5 Open core gasifier

(e) Fluidized Bed Gasifiers

Fluidized bed gasification (figure 6) is originally developed to overcome the operational problems with fixed bed gasification of fuels with high ash content. Compared to fixed bed gasifiers the gasification temperature is relatively low, appr. 750-900 °C. In fixed bed gasifiers the temperature in the hearth zone is around 1200 °C, in charcoal gasifiers is 1500 °C. In fluidized bed gasifier the fuel is fed into a hot (sand) bed and circulated. Fuel particles mix very quickly with the bed material due to high turbulence and produce large amount of pyrolysis gases. Fluidized bed gasifiers are most useful for fuels that form highly corrosive ash that would damage the walls of slagging gasifiers. Biomass fuels generally contain high levels of corrosive ash.

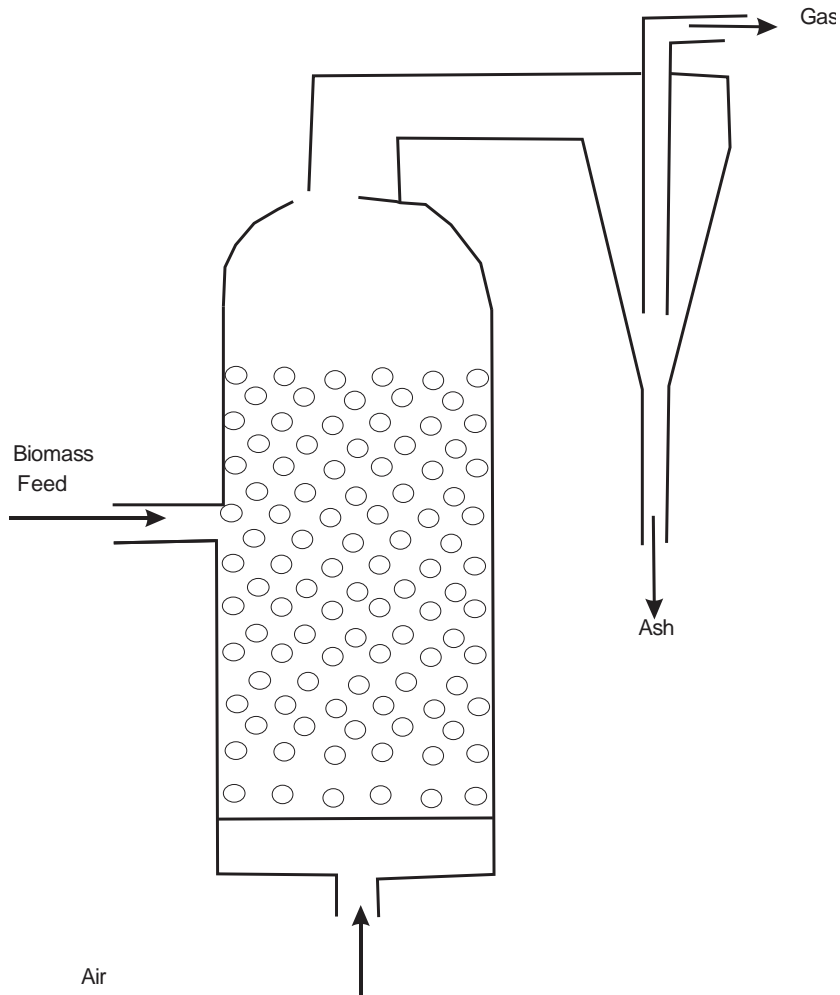


Figure 1.2.6 Fluidized Bed Gasifier

Waste gasification has several advantages over incineration:

- Production of syngas can be used to generate electric power in engines, fuel cells and gas turbines very efficiently.
- Chemical processing of the syngas (gas to liquids) may produce other synthetic fuels instead of electricity.

1.2.1.5 Current applications

Gasification can proceed from any organic material, including biomass and plastic waste. The resulting syngas can be combusted. Syngas can be used for heat production and for generation of mechanical and electrical power.

They can be used for further processing to liquid fuels or chemicals. Heating value of syngas are generally around 4-10 MJ/m³. If the syngas is clean enough, it may be used for power production in gas engines, gas turbines or fuel cells, or converted efficiently to dimethyl ether (DME) by methanol dehydration, methane via the reaction with hydrogen and carbon dioxide or diesel-like synthetic fuel via the reaction of hydrogen and carbon monoxide. Currently Industrial-scale gasification is used to produce electricity from fossil fuels such as coal, where the syngas is burned in a gas turbine. Gasification is used industrially in the production of electricity, ammonia and liquid fuels (oil). In small business and building applications, where the wood source is sustainable, syngas from wood can be burnt in reciprocating engines connected to a generator with heat recovery. They can be used as transport fuels also. Diesel engines can be operated on dual fuel mode using producer gas. Solid oxide fuel cells can operate on 100% gasification gas.

1.2.2 Pyrolysis

Pyrolysis systems thermally degrade solid waste usually without the addition of any air or oxygen. The process is more suitable when the input waste is organic or carbon-rich, sorted or pre-sorted materials. It is a type of thermolysis, and is most commonly observed in organic materials exposed to high temperatures. The process is similar to gasification but generally optimized for the production of fuel liquids or pyrolysis oils (sometimes called bio-oils if biomass feedstock is used) and leaves a solid residue as rich carbon content char. Pyrolysis liquids can be used directly (boiler fuel and in some stationary engines) or refined for higher quality uses such as motor fuels, chemicals, adhesives, and other products.

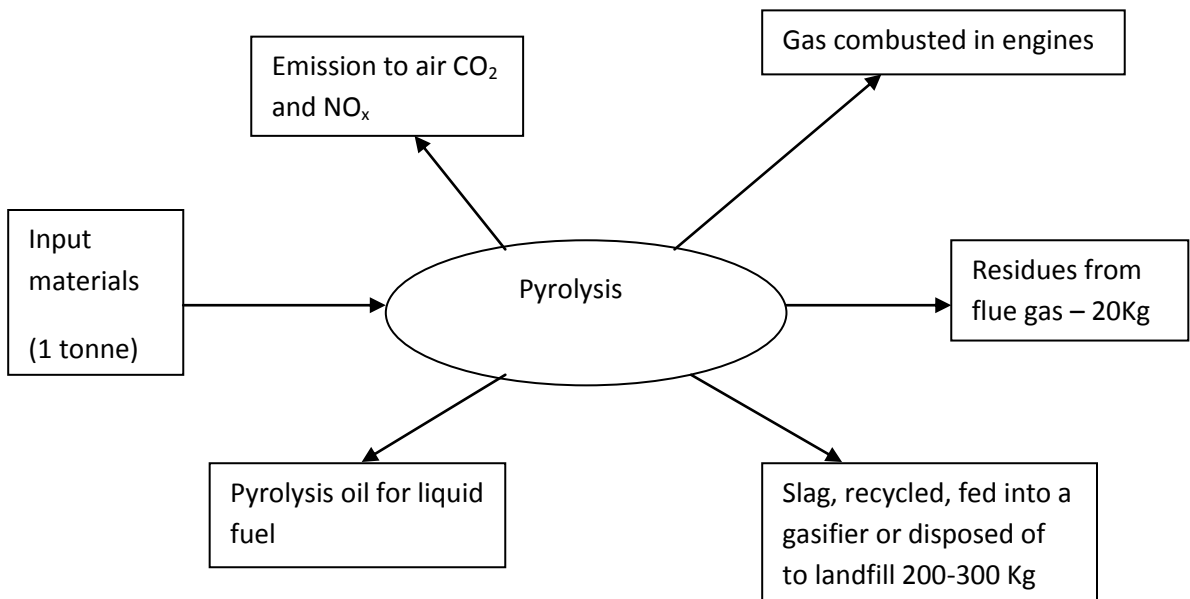


Figure 1.2.7 Schematic of Inputs and Outputs of a typical Pyrolysis process

The general characteristics of pyrolysis of a waste stream are given below.

1. No or very less oxygen is present
2. Low temperatures typically from 300 °C to 800 °C

3. Products are syngas (mainly carbon monoxide, hydrogen, methane and some longer chain hydrocarbons including condensable tars, waxes and oils) and a solid residue (consisting of non-combustible material and a significant amount of carbon)
4. converts less of the chemical energy into thermal energy

Pyrolysis generally takes place at lower temperatures than for combustion and gasification. The result is less volatilization of carbon and certain other pollutants such as heavy metals and dioxin into gaseous stream. Any pollutant that is not volatilized will be retained in the pyrolysis residues. The solid residues from some pyrolysis processes could contain up to 40% of the energy from the input waste. Recovery of the energy from the char is important for energy efficiency.

The process is used heavily in the chemical industry to produce charcoal, activated carbon, methanol, and other chemicals from wood. Pyrolysis plays an important role in several cooking procedures, such as baking, frying, grilling, and caramelizing. It is also a tool of chemical analysis in mass spectroscopy and in carbon-14 dating. Many important chemical substances, such as phosphorus and sulfuric acid, were first obtained by this process. Pyrolysis has been assumed to take place during catagenesis, the conversion of buried organic matter to fossil fuels.

1.2.3 Plasma gasification

Plasma gasification is a process that converts organic materials into synthetic gas, electricity and solid residues using plasma. A plasma is used as plasma torch powered by electric arc. . Plasma torch uses argon gas. Electric arc consists of two electrodes (copper, zirconium or other alloys) that pass high voltage electric current. Plasma is created by the arc and inert gas or argon is ionized and catalyzed organic matter into syngas and solid residues. The temperature of the torch ranges from 2,200 to 13,900C. The byproducts of this process or oxidation are CO₂, N₂, H₂O etc.

Through this process waste is heated, melted and finally vaporised. At these conditions molecular bonds are broken and complex molecules are separated into individual atoms. . This molecular dissociation is referred as Plasma Pyrolysis.

Plasma gasification can be applied to treat municipal solid waste, biomedical or hazard waste. Composition of the waste directly impacts performance of a plasma facility. Large solid byproduct and less syngas is produced when

the waste consist more inorganic materials. Shredding waste before entering the main chamber helps to increase syngas production. This creates an efficient transfer of energy from large molecular waste. The lack of oxygen prevents the formation of many toxic materials. The high temperatures in a reactor also prevent the main components of the gas from forming toxic compounds such as furans, dioxins, nitrogen oxides or sulfur dioxide. The conversion rate of plasma gasification exceeds 99%. A portion of the syngas produced feeds on-site turbines, which power the plasma torches and support the feed system.

2 Non-thermal technologies

2.1 Anaerobic Digestion (AD)

Anaerobic digestion is widely used as a source of renewable energy reducing emission of landfill gas into the atmosphere. Anaerobic digestion (AD), known as biogas technologies, are designed to control and optimize the biological digestion of biodegradable materials to produce methane gas for energy production. The process of Anaerobic Digestion (AD) employs specialized bacteria to break down organic waste into biogas (mixture of carbon dioxide and methane) and a partially stabilised wet organic mixture (digestate) in the absence of oxygen. Many microorganisms affect anaerobic digestion, including acetic acid-forming bacteria (acetogens) and methane-forming bacteria (methanogens). These organisms promote a number of chemical processes in converting the biomass to biogas. The process produces a biogas, consisting of methane, carbon dioxide and traces of other contaminant gases. This biogas can be used directly as fuel, in combined heat and power gas engines or upgraded to natural gas-quality bio-methane. Also this process is used for industrial or domestic purposes to manage waste and/or to produce fuels.

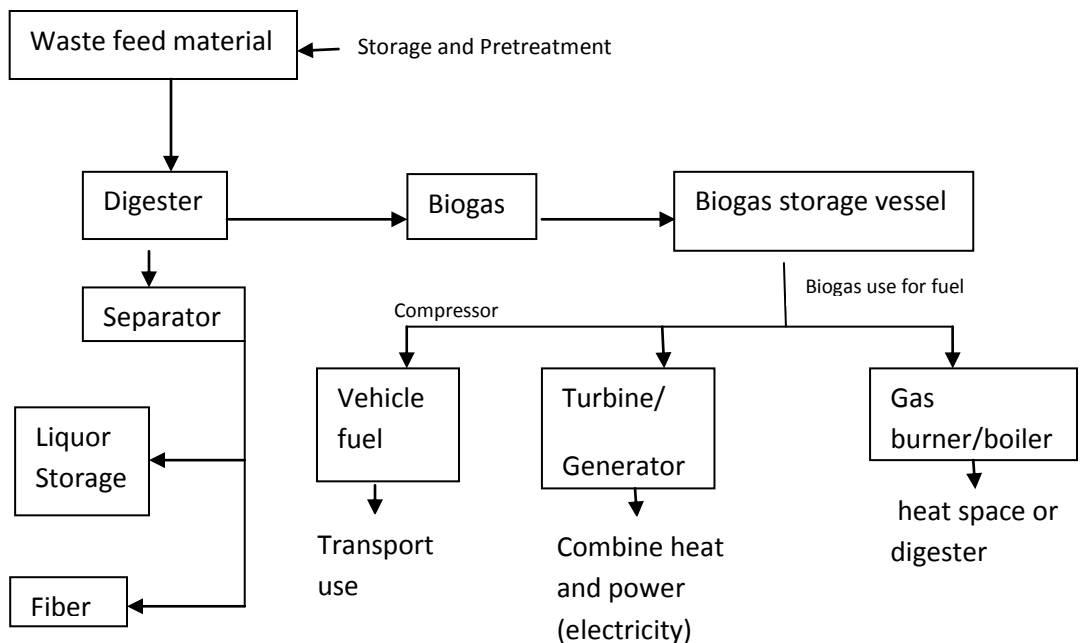


Figure 2.1.1 Flow Chart of the Anaerobic Digestion

The amount of biogas produced using AD will vary depending on the process design, such as retention times and operation temperature, and the volatile solids (organic matter) content of the feedstock.

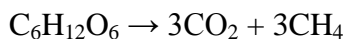
The solid fraction produced from digestion process can be mechanically pressed into its solids (digestate) and liquid (liquor) fractions. The dewatered digestate may be used directly on land as a soil amendment provided it meets appropriate regulatory standards, or aerobically treated to produce compost. Liquor fraction may be recycled in the AD process or can be used directly on land as a liquid fertilizer due to its valuable nitrogen content or treated and discharged in accordance with permit requirements.

2.1.2 Digestion processes

2.1.2.1 Fundamental stages of Anaerobic Digestion

The digestion process begins with hydrogenise bacteria of the input materials. Insoluble organic polymers, such as carbohydrates, are broken down to soluble derivatives which are used by other bacteria. Acidogenic bacteria convert the sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acids. Finally, methanogens convert these products to methane and carbon dioxide.

The four key stages of anaerobic digestion involve hydrolysis, acidogenesis, acetogenesis and methanogenesis. The overall process can be described by the chemical reaction, where organic material such as glucose is biochemically digested into carbon dioxide (CO₂) and methane (CH₄) by the anaerobic microorganisms.



Temperature is a key component to the efficiency of anaerobic digesters. The two most widely used types of microorganisms are mesophiles, which undergo mesophilic digestion, and thermophiles, which undergo thermophilic digestion. Mesophiles are most efficient at moderate temperature ranges between 25-40°C while thermophiles run most efficiently at higher ranges between 45-80°C. The temperature is monitored during the digestion process and kept in the upper portion of the specific range given. Higher temperatures produce higher gas yields. But it is more difficult and expensive to maintain making temperature a vital aspect to measure throughout the digestion process.

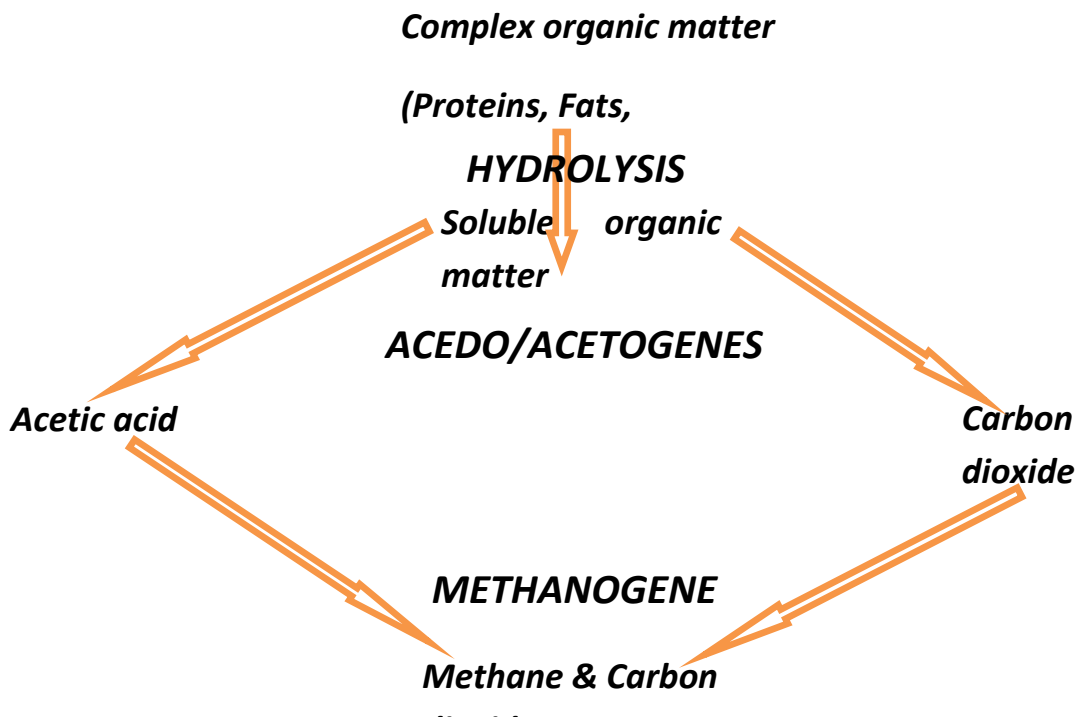


Figure 2.1.2 AD Main Stages

Biogas production rate is also a key component to maximizing anaerobic digestion efficiency. It is vital to constantly measure biogas emissions (methane, carbon dioxide, trace amounts of siloxanes, hydrogen sulfide, ammonia, hydrocarbons, and water) as the production levels.

In anaerobic digestion, it is crucial to measure the pH throughout the entire process to ensure the health of the methanogens. The microorganisms that are responsible for the production of methane require an environment between the pH ranges of 6.5-8. Being that in the process of acidogenesis, acidogenic bacteria produce acid, which thus lowers the pH (less than 4) of the digestion tank. Therefore it is necessary to constantly measure the pH throughout the entire process to ensure the continued wellbeing of the methanogens and thus, methane production.

Table 2.1 Produce Bio gas Composition in Anaerobic Digestion

Approximate Biogas Composition in Anaerobic Digestion	
Gas	Concentration %
CH ₄	50-70
CO ₂	25-30
N ₂	0-10
H ₂ O	0-5
H ₂ S	0-3
O ₂	0-3
C _x H _y	0-1
NH ₃	0-0.5
R ₂ SiO	0-50 mg/m ³

In anaerobic digestion, hydrolysis is the essential first step. In most cases, biomass is made up of large organic polymers (proteins, fats and carbohydrates). Through hydrolysis, these large polymers are broken down into smaller molecules such as amino acids, fatty acids, and simple sugars. While some of the products of hydrolysis, including hydrogen and acetate, may be used by methanogens later in the anaerobic digestion process, the majority of the molecules, which are still relatively large, must be further broken down in the process of acidogenesis so that they may be used to create methane.

The process of hydrolysis is the broken down these large polymers to smaller constituent parts such as sugars, amino acids and fatty acids which are used other bacteria. Therefore, hydrolysis of these high molecular weight polymeric components is the necessary first step in anaerobic digestion.

(a) Acidogenesis

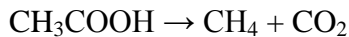
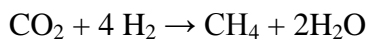
Acidogenesis is the next step of anaerobic digestion in which acidogenic microorganisms further break down the biomass products after hydrolysis. These fermentative bacteria produce an acidic environment in the digestive tank while creating ammonia, H₂, CO₂, H₂S, shorter volatile fatty acids, carbonic acids, alcohols, as well as trace amounts of other byproducts. While acidogenic bacteria further breaks down the organic matter, it is still too large and unusable for the ultimate goal of methane production, so the biomass must next undergo the process of acetogenesis.

(b) Acetogenesis

The third stage of anaerobic digestion is acetogenesis. In this stage, simple molecules that created through the acidogenesis phase are further digested by acetogens to produce largely acetic acid, as well as carbon dioxide and hydrogen. Methanogens can utilize much of the remaining material to create methane as a Biofuel.

(c) Methanogenesis

The terminal stage of anaerobic digestion is the biological process of methanogenesis. Methanogens use the intermediate products of the preceding stages and convert them into methane, carbon dioxide, and water. These components make up the majority of the biogas emitted from the system. Methanogenesis is sensitive to both high and low pHs and occurs between pH 6.5 and pH 8. The remaining indigestible material which cannot be used by microbes and any dead bacterial remain as digestate. While CO₂ can be converted into methane and water through the reaction, the main mechanism to create methane in methanogenesis is the path involving acetic acid. This path creates methane and CO₂, the two main products of anaerobic digestion.



Anaerobic digesters can be designed and engineered to operate using a number of different configurations and can be categorized into batch vs. continuous process mode, mesophilic vs. thermophilic temperature conditions, high vs. low portion of solids, and single stage vs. multistage processes.

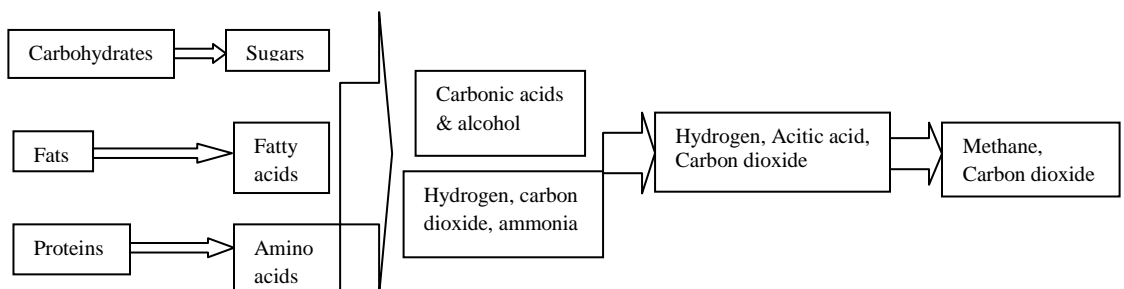


Figure 2.1.3 The key process stages of anaerobic digestion

2.1.3 Batch or continuous test

Anaerobic digestion can be performed as a batch process or a continuous process. In a batch system biomass is added to the reactor at the start of the process. The reactor is then sealed for the duration of the process. Biogas production will be formed with a normal distribution pattern over time. There can be severe odour issues if a batch reactor is opened and emptied before the process is well completed. After anaerobic digestion has completed, the biomass is kept in the reactor for in-vessel composting before it is opened. As the batch digestion is simple and requires less equipment and lower levels of design work, it is typically a cheaper form of digestion. Using more than one batch reactor at a plant can ensure constant production of biogas.

In continuous digestion processes, organic matter is constantly added (continuous complete mixed) or added in stages to the reactor (continuous plug flow; first in – first out). The end products are constantly or periodically removed, resulting in constant production of biogas. A single or multiple digesters may be used. This form of anaerobic digestion includes continuous stirred-tank reactors, upflow anaerobic sludge blankets, expanded granular sludge beds and internal circulation reactors.

The two conventional operational temperature levels for anaerobic digesters determine the species of methanogens in the digesters:

1. Mesophilic digestion takes place optimally around 30 to 38 °C, or at ambient temperatures between 20 and 45 °C, where mesophiles are the primary microorganism present.
2. Thermophilic digestion takes place optimally around 49 to 57 °C, or at elevated temperatures up to 70 °C, where thermophiles are the primary microorganisms present.

There are two main classifications of AD techniques as ‘wet’ and ‘dry’ process. Wet AD systems process more liquid materials (85% moisture), whereas ‘dry’ AD processes are used to treat drier materials (80% moisture) ranging from thick slurry to a wet solid.

(a) “Dry” AD technology

“Dry” AD processes are used to treat dry materials (80% moisture). Dry technologies can comprise vertical or horizontal tanks and use plug flow

reactor designs. This approach involves adding fresh waste and/or partially fermented waste into one end of the reactor while fully digested residue is extracted from the other. In vertical tanks, materials move through the system according to gravity, whereas horizontal systems use specialised augers to move materials to the end of the system. AD technologies can be operated at moderate (mesophilic: 30 – 40°C) temperatures or high (thermophilic: 50 – 60°C) temperatures. ‘Dry’ AD processes lend themselves to thermophilic operation due to higher solids content and greater biological heat production. Solid fraction of the process is undergone a further stabilized as compost. The composting system uses the “open air windrow” composting process.

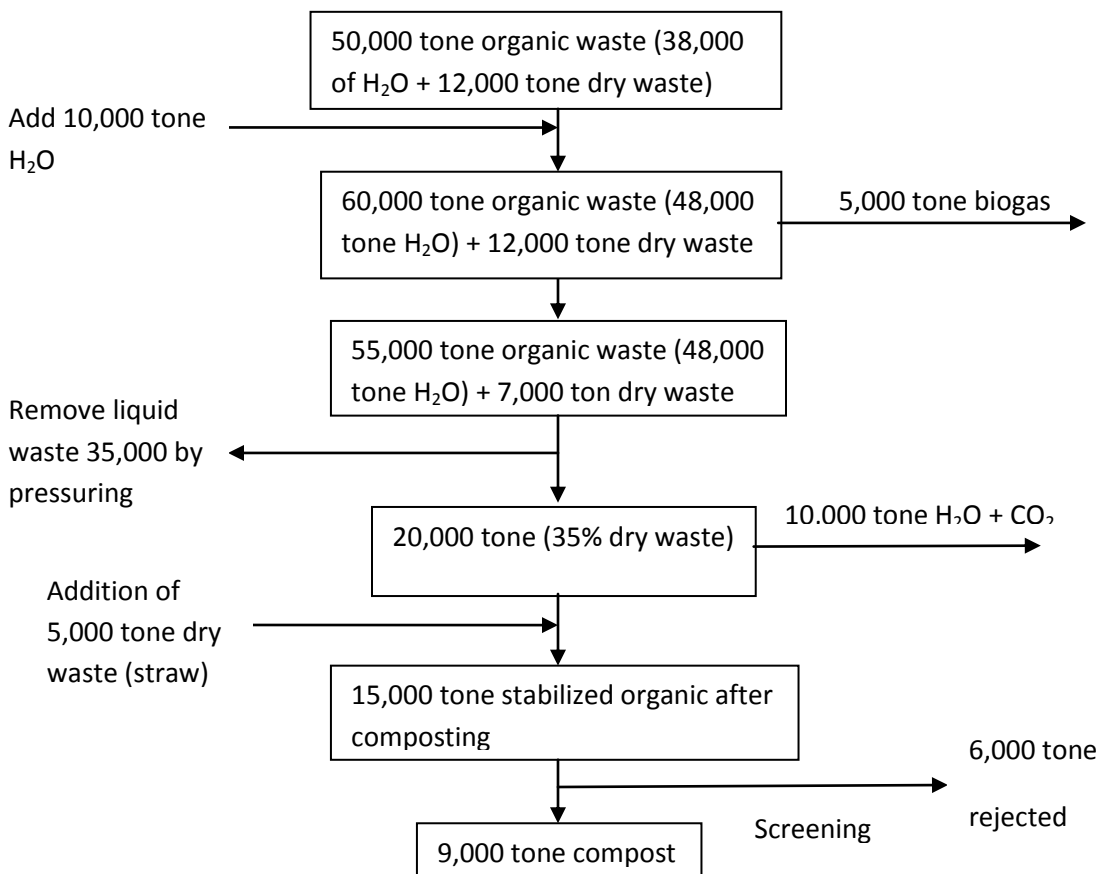


Figure 2.1.4 Process Mass Flow Diagram

Regarding the heat requirements of the AD process, one third of the biogas produced is needed to heat the digester itself. Maximum two thirds of the heat produced by agricultural biogas plants can be used in some way under practical operating conditions. Arcadis et al. (2010) assumes that the AD process utilizes 30 kWh of electricity and 118 kWh of heat per ton of input to the process, equivalent to 10% of electricity generated, and 33% of the heat generation.

These energy requirements are supplied by the AD process itself with energy exploitation of biogas produced. The amount of produced biogas, which methane content is 55-65%, depends on the composition of feedstock. Comparatively little information is available on the amount of biogas produced by different feedstocks in an anaerobic digester. The only pure research is from bench-scale studies carried for the USEPA, where the relative contributions of different materials to landfill gas generation (through anaerobic digestion) were measured. Results of this work, according to RIS et al. (2005), are presented in the following table.

Table 2.2 Amount of biogas production in different materials

Material	Moisture (% wt)	Biogas Yield m ³ /Kg of material feed
Paper		
Newspaper		0.061
Cardboard/Boxboard	10	0.125
Telephone directories	10	0.061
Office paper	10	0.178
Mixed paper	10	0.112
Kitchen waste		
Food	70	0.113
Yard waste		
Grass	60	0.034
Leaves		0.023
Brush	40	0.067
Other organic		0.101

The amount of water added in the digester in dry systems is pumped back to plant, while other facilities recirculate liquid from the digester either within the digester or reuse it as process water (RIS et al. 2005). According to IPPC

BREF (European Commission, 2006) the total fresh water consumption for treatment of 1 tonne of organic waste is 78 kg. According to data from various existing facilities (ARI et al. 2008; RIS et al. 2005) biogas production ranges from 50 m³ to 150 m³ per ton of feedstock, with the lower values being characteristics of systems with shorter retention time.

Anaerobic systems generate less emission than aerobic systems per kilogram of waste, since the principal gaseous emission (methane) is a desired product. However emissions related to the delivery of waste and mechanical treatment may cause emissions of odours and dust and the anaerobic digestion of the digestate may cause a significant odour problem if not properly treated. CO₂ emitted from AD is not considered as a greenhouse gas emission. According to IPPC BREF (European Commission, 2006a) emissions of CH₄ are less than 1% of the total CH₄ content of the biogas, ranging from 0 to 411 g per tonne of organic waste treated, while N₂O emissions are assumed minimal.

(b) “Wet” AD technology

“Wet” AD systems used to treat municipal solid waste have been accompanied with well established systems to treat wastewater treatment plant biosolids. The digestion process takes place in sealed vertical tanks (digesters). Within the tank microbes and waste continuously mixed and contact together. Mixing can be achieved using mechanical stirring devices, or by recirculating biogas through the digestion tank. Transfer of material between several tanks is achieved through pumps. This type of wet system is suited for food waste. In ‘wet’ AD systems heavy and light contaminants moved through the mixture by wet gravimetric separation. Wet’ AD processes can be operated at the temperature between 30-60°C including mesophilic and thermophilic conditions. In wet AD systems two reactors are used to operate as a “two-step” process. In the first reactor hydrolysis takes place and in the second reactor methanogenesis takes place.

2.2 Fermentation

2.2.1 Complete Dry AD (Dry Fermentation)

Complete Dry AD, or Dry Fermentation is a relatively new **anaerobic process**, similar as anaerobic digestion. The technique is simpler in construction. Dry fermentation does not require the adding of water to the organic waste since it operates at 50% dry matter content. The process takes place inside a simple, closed container and waste must take place in order to

separate the organic fraction from the other. The organic matter is inoculated with substrate that has already been fermented. It is then filled into the digester and fermented under airtight conditions. Continual inoculation with bacterial matter occurs through recirculation of leachate within the reactor. No stirring of the organic matter is necessary during the dry fermentation process, as it is in conventional AD systems.

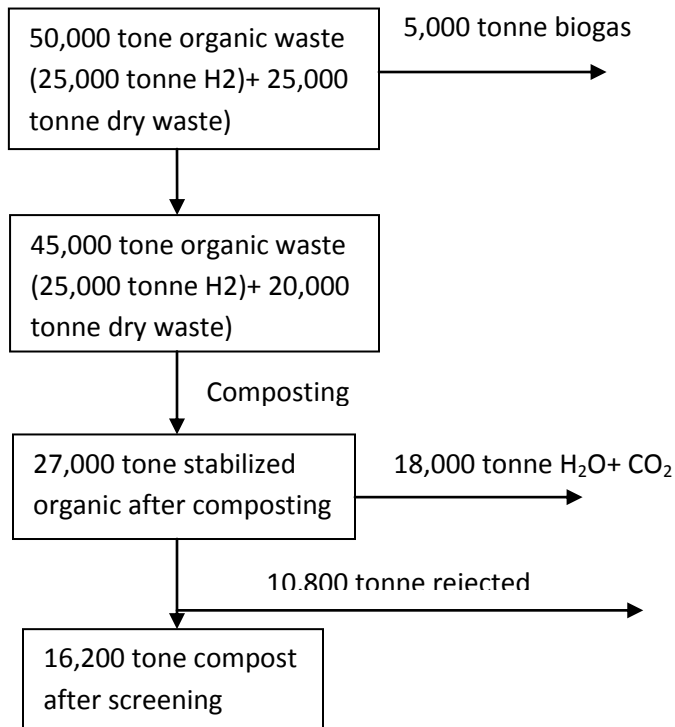


Figure 2.2.1 Process Mass Flow Diagram

The different stages of degradation (hydrolysis, acid and methane formation) take place in the same digester. The process is operated in a batch manner. Products include biogas and digestate. Digestate does not need to be treated to separate the solid and liquid phase as digestate is composted (matured) in covered windrows.

2.3 Mechanical Biological Treatment (MBT)

Mechanical Biological Treatment (MBT) is a residual waste treatment process that involves both mechanical and biological treatment. It is an integration of several processes commonly found in waste management

processes such as Materials Recovery Facilities (MRFs), Refuse Derived Fuel (RDF), sorting and composting plant. MBT is stabilized and separated the residual waste stream into less harmful and / or more beneficial output streams. There are several sub processes in MBT as follows to achieve its aims of the treatment process.

- Stage I Preparation or pre-treatment of waste
- Stage II Diversion of non-biodegradable and biodegradable MSW
- Stage III Stabilization into a compost like output for land use practices
- Stage IV Conversion into biogas or energy
- Stage V Produce high calorific organic rich fraction of residual derived fuel (RDF)

Residual waste requires preparation before biological treatment or sorting of materials. Initial waste preparation may take the form of simple removing bulky wastes such as mattresses, carpets which could cause problems with processing. Further mechanical waste preparation techniques may be used to separate waste materials. The recyclable component may be extracted either prior to or post 'stabilisation'. The remainder of the waste is sorted to produce either a feedstock for another treatment process. There is usually a minor non combustible element sent for disposal to landfill. Some systems may screen the waste to produce a compostable stream where the waste is to be used as a secondary fuel. An alternative MBT approach is the extraction of recyclables followed by homogenization of the residue prior to processing in an Anaerobic Digestion plant. Output of the MBT can be used for low grade land restoration or subsequent thermal treatment.

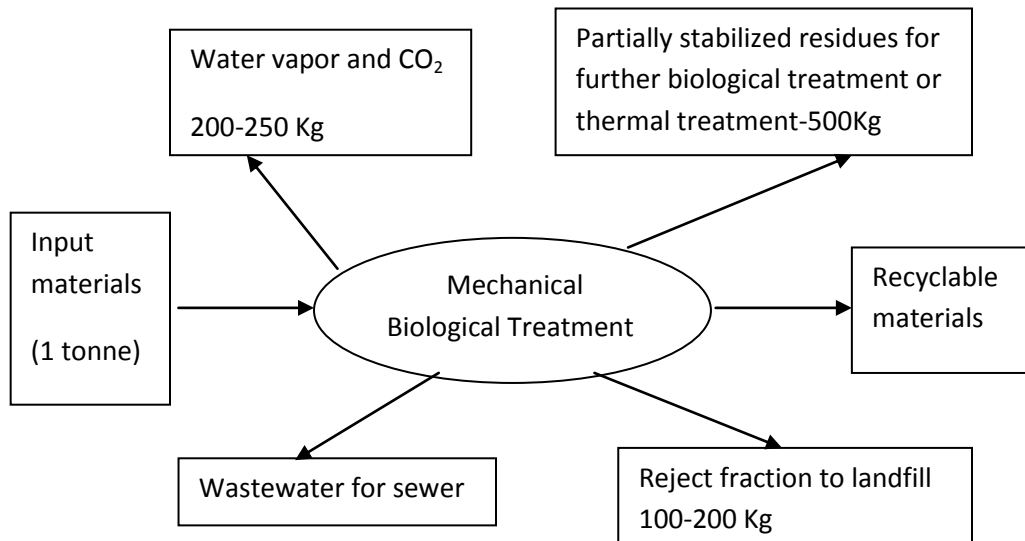


Figure 2.3.1 Input and out put of Mechanical Biological Treatment Process

References

1. CIWM Mechanical Biological Treatment guidance:
http://www.ciwm.co.uk/CIWM/InformationCentre/AtoZ/MPages/Mechanical_Biological_Treatment.aspx.
2. DCLG planning guidance:
<http://www.communities.gov.uk/planningandbuilding/planningenvironment/>.
3. Designing Waste Facilities: A Guide to Modern Design in Waste, Defra, 2008:
<http://archive.defra.gov.uk/environment/waste/localauth/documents/designingwaste-facilities-guide.pdf>.
4. England's Waste Infrastructure: Report on facilities covered by environmental permitting: 2010, Environment Agency, October 2011:
<http://www.environment-agency.gov.uk/research/library/data/134327.aspx>.
5. General organics recycling information available from:
<http://www.organics-recycling.org.uk/>,
6. <http://www.wrap.org.uk/>, <http://www.nnfcc.co.uk/> and
<http://www.adbiogas.co.uk/>.
7. Integrated Pollution Prevention and Control, Reference Document on Best Available Techniques for the Waste Treatments Industries, European Commission – Directorate General Joint Research Centre, August 2006:
http://ec.europa.eu/environment/ippc/brefs/wt_bref_0806.pdf.
8. Local Authority funding:
<http://www.defra.gov.uk/environment/waste/local-authorities/widp/>.
9. <http://www.wrap.org.uk/content/bsi-pas-100-compost-specification>.
10. PAS 110:2010 Specification for whole digestate, separated liquor and separated fibre derived from the anaerobic digestion of source-segregated biodegradable materials, BSi, February 2010:
<http://www.wrap.org.uk/content/bsi-pas-110-specification-digestate>
11. Quality Protocol: Anaerobic Digestate: End of waste criteria for the production and use of quality outputs from anaerobic digestion of source-segregated biodegradable waste, Environment Agency and WRAP, 2010:

- [http://www.environmentagency.gov.uk/static/documents/Business/W524AnaerobicDigestev4\(1\).pdf](http://www.environmentagency.gov.uk/static/documents/Business/W524AnaerobicDigestev4(1).pdf).
12. Chandler, A. John. September (1997). "Municipal solid waste incineration technologies." A presentation for the World Bank Seminar on Waste Management by A.J.Chandler & Associates Ltd. Ontario, Canada.
 13. McCARTHY and RAMBØLL J.V.(1998). Richmond Hill Incinerator, Final Summary Report. Isle of Man Government.
 14. RAMBØLL. September (1993). "Review of Taiwan Tender Document & Plant Design Specification." China Engineering Consultants, Inc.
 15. Hjelmar, O. (1996). Disposal Strategies for Municipal Solid Waste Incinerator Residues. Journal of Hazardous Materials
 16. A.J. Chandler, T.T. Eighmy, J. Hartlén O. Hjelmar, D.S. Kosson, S.E. Sawell, H.A. van der Sloot, J. Vehlow.(1997). Municipal solid waste incinerator residues. Studies in Environmental Science 67, Elsevier Science B.V., Amsterdam.
 17. Review of Environmental & Health Effects of Waste Management (2004). Enviros Consulting Ltd, University of Birmingham, Open University & Maggie Thurgood, Defra:
<http://archive.defra.gov.uk/environment/waste/statistics/documents/healthreport.pdf>.
 18. Renewables Obligation (RO), Renewable Heat Incentives (RHI) and Feed-in-Tariffs (FiTs) guidance:
http://www.decc.gov.uk/en/content/cms/funding/funding_ops/funding_ops.aspx.
 19. Rubbish to Resource: Financing New Waste Infrastructure, Associate Parliamentary Sustainable Resource Group (APSRG), September 2011:
<http://www.policyconnect.org.uk/apsrg/rubbish-resource-financing-new-wasteinfrastructure>
 20. 'Waste Management Infrastructure: Incentivising Community Buy-In', APSRG, February 2011:
<http://www.policyconnect.org.uk/apsrg/waste-managementinfrastructure-incentivising-community-buy>