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Alternative Energy from Waste

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ABSTRACT

Municipal solid waste management is one of the major problems in almost all major cities all over the world. A variety of technologies have been employed to manage the problem of solid waste as well as the conversion of waste to clean energy. The constant rise in the world's population invariably gives rise to more waste production as well as rise in energy demands which places a strain on already existing energy resources like fossil. Waste in the 21st century is no more seen as 'waste' as it were but a resource which can be transformed into various forms and uses like energy. Therefore waste multi-reuse and conversion should be given priority in developing countries, for a better solution of waste control and management. This will not only reduce the ecological and environmental damage caused by pollution, but also reduce the energy demand and consumption and, thus, save primary energy. This paper presents the challenge of waste in the environment and makes a case for the potential of converting this waste to energy. It further discusses six methods of waste to energy conversion, their environmental impacts, merits and demerits of each method and finally gives recommendations for use cases for each method.

Keywords— Conversion, Energy, Environment, Waste

I. INTRODUCTION

Waste

As entropy cannot be zero according to the laws of thermodynamics, so also the society's ultimate goal for zero waste (matter/energy) might seem far-fetched except all human activity is put to a halt which in itself is impossible. As long as humans carry out daily activities, waste as a phenomenon is a constant. So, in all processes, some unused matter will always result to waste produce. Hence, it is difficult to have a waste free society, however, by control of waste production and proper management, it can be brought to a tolerance level. There are several ways to manage waste and one of the best ways to manage waste is to convert it to a useful resource or product. Several world environmental agencies have come up with several ways to manage waste like the 3R concept (recycle, re-use and reduce). Our focus however is waste conversion to energy.

According to the World Bank Group records on global waste generation, the world generates 1.3 billion tonnes of Municipal Solid Waste (MSW) annually. By 2025 the world could generate 2.2 billion tonnes of MSW per year. Such a prediction forces us to consider and develop alternatives for addressing our future waste management (WM) challenges [1].

A part of the solution to waste management will be Waste to Energy (WTE) technologies which will help facilitate sustainable WM programs by converting waste to energy production. Unfortunately, WTE practices are still underutilized especially in developing countries.

Municipal Solid Waste (MSW) to a large extent is of biological origin (biogenic) like cloth, food scraps etc. therefore, half of the energy content in MSW is from biogenic material [2]. Consequently, this energy (from waste) is often recognized as renewable energy, however, dependent on what the waste material is made up of [3].

Waste is defined as unwanted or unusable material, substance or byproducts. They are substances that are discarded after primary use or is worthless, defective and of no use. Examples include municipal solid waste (household trash/refuse), hazardous waste, waste-water (such as sewage which contains bodily wastes (feces and urine) and surface Run-off), radioactive waste and others.

Waste is a consequence of everyday life of all creatures with particular emphasis on humans [4] and is directly linked to human development, both technologically and socially. It refers to by-products or unwanted materials resulting from human activities like construction, manufacturing, transportation or domestic processes. The compositions of different wastes have varied over time and location, with industrial development and innovation being directly linked to waste production. Some components of waste have economic value and can be recycled once correctly recovered.

Waste is sometimes a subjective concept, because items that some people discard may have value to others. It is widely recognized that waste materials are a valuable resource, whilst there is debate as to how this value is best realized [5]. However, when waste is not properly controlled or managed, it poses a threat to both the environment and humans.

Waste can be classified as;

- Biodegradable waste or
- Non-biodegradable waste

Biodegradable waste is a type of waste that originates from plant or animal sources, which may be

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degraded by other living organisms like food waste commonly found in biodegradable municipal waste. Others include slaughterhouse waste, human waste, sewage etc. Non-biodegradable waste on the other hand are waste that cannot be broken down by other living organisms.

There are many waste types defined by modern systems of waste management, notably including Municipal solid waste (MSW): Construction waste and demolition waste (C & D), Institutional waste, commercial waste, and industrial waste (IC & I), Medical waste (also known as clinical waste), Hazardous waste, radioactive waste and electronic waste (e-waste), Biodegradable waste [5], For the purpose of this study, emphasis will be on convertible waste.

Energy

Energy as we know, is the cause behind the motion of particles or objects which characterize the several activities that take place in nature. Energy is the capability to produce motion, force, work, change in shape, change in form etc. and can exist in several forms such as chemical energy (Ech), nuclear energy(Enu), electrical energy (Eec), mechanical Energy (Eme), solar energy (Eso), internal energy in a body (Ein), bio-energy in vegetables and animal bodies(Ebi), thermal energy (Eth) etc.

Energy can be classified as:

- Primary or raw energy: energy available in nature,
- Intermediate Energy: energy obtained from primary energy resources by one or more processes while
- Secondary or usable Energy is energy supplied to the consumer for final consumption or utilization. [6].

Usable Energy is therefore the power derived from the utilization of physical or chemical resources, especially to provide light and heat or to work machines which can be transformed from one form to another but never destroyed according to the law of conservation of energy. Energy is required to produce heat and energy and all forms of human activities revolve around energy. There is a steady increase in the demand for energy as the world's population experiences steady growth.

II. WASTE TO ENERGY

Waste-to-energy (WTE), also known as, energy-from-waste (EFW) is the process of generating energy in the form of electricity or heat from the primary treatment of waste, or the process of converting waste into a fuel source. WTE is a form of energy recovery. Most WTE processes generate electricity or heat directly through combustion, or produce a combustible fuel commodity, such as methane, methanol, ethanol or synthetic fuels [7]. The major forms of energy that can be derived from waste are thermal energy and bio-energy.

Waste to Energy (WTE) as a term describes various technologies that convert non-recyclable waste into useable forms of energy including heat, fuels and electricity. WTE can occur through a number of processes such as incineration, gasification, pyrolysis, anaerobic digestion and landfill gas recovery [21].

There are a number of new and emerging technologies that are able to produce energy from waste and other fuels.

III. WASTE TO ENERGY CONVERSION TECHNOLOGIES

Incineration

Incineration, the most common and one of the oldest WTE implementation is a waste treatment process that involves the combustion of organic material such as waste with energy recovery. Incineration and other high temperature waste treatment systems are described as "thermal treatment". Incineration 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 gas must be cleaned of gaseous and particulate pollutants before they are dispersed into the atmosphere [9].

Modern incineration plants are vastly different from old types, some of which neither recovered energy nor materials. Modern incinerators reduce the volume of the original waste by 95-96 percent, depending upon composition and degree of recovery of materials such as metals from the ash for recycling [10] and clean flue gases before emission.

Incineration Process

The modern incinerator is an efficient combustion system with sophisticated gas clean-up which produces energy and reduces the waste to an inert residue with minimum pollution.

The fuel properties of the waste, the proximate analysis (ash, moisture, volatile contents), and the ultimate (elemental) analysis are important factors to consider in assessing how the waste will burn in the incinerator and the emissions which are likely to result. The incineration process typically has four phases; pretreatment, combustion, energy recovery and cleaning.

Pretreatment: The sludge is typically subjected to thickening, dewatering and/or drying treatments to increase the total solids content (>25%) and calorific value to make the material suitable for incineration.

Combustion: The material is fed into the furnace along with compressed air for combustion. The furnace types used include fluidised-bed, multiple-hearth or rotary kilns. The first option has become the most popular choice for sewage sludge incineration as it is easier to operate, with no mechanical moving parts, leading to less wear on

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the equipment, and it also offers more flexibility with intermittent operation available. During heating, at temperatures typically ranging up to 850–950°C, the volatile and organic components are burnt off as gases and are conveyed out of the furnace chamber along with the fine particulate inorganic matter and, in certain plants, bottom ash residue is collected.

***Energy recovery*:** The hot gases exiting the furnace pass through an energy recovery system, whereby the energy can be recovered in the form of heat or electricity. The heat can be used for heating the combustion air or for pre-drying sewage sludge before combustion.

Cleaning system: Flue gases produced during the combustion of sewage sludge are conveyed through a controlled cleaning process. Ash, dust and harmful gases are removed typically using scrubber units, whilst electrostatic precipitators and fabric filters are used at times, primarily when co-fired with municipal solid waste, to achieve compliance with emission limits.

Benefits of Incineration

Incineration burns completely combusted waste at ultra-high temperatures allowing for energy recovery. Modern incineration facilities use pollution control equipment to prevent the release of emissions into the environment. Incineration WTE technology is economically viable and operationally feasible at commercial scale.

Although, pyrolysis, can thermo-chemically convert waste products into clean liquid fuels, incineration has particularly strong benefit for the treatment of certain waste types in niche areas such as clinical wastes and certain hazardous waste where pathogens and toxins can be destroyed by high temperature.

Limitations of Incineration

The air pollution control systems are very expensive. On the other hand, the emissions and the ash resulting from incinerators without the pollution control system, typically, the old ones, are extremely dangerous. They may emit fine particulate, heavy metals, trace dioxin and acid gas. Although these emissions are relatively low from modern incinerators.

Other concerns may include proper management of residues: toxic fly ash, which must be handled in hazardous waste disposal installation as well as incinerator bottom ash (IBA), which must be reused. [11]. If not properly controlled, they cause air pollution that can have dangerous effects on human health.

It is believed by critics that incinerators destroy valuable resources and they may reduce incentives for recycling. However, most countries that recycle the most (up to 70%) also incinerate to avoid landfilling. (European Union. 2012). The economic viability of incineration as a waste treatment and disposal route for municipal waste depends on the recovery of energy from the process to offset the high costs involved in incineration.

Application of Incineration

The method of incineration to convert municipal solid waste (MSW) is a relatively old method of WTE generation. Incineration generally entails burning waste (residual MSW, commercial, industrial and RDF) to boil water which powers steam generators that generate electric energy and heat to be used in homes, businesses, institutions and industries. Incinerators have electric efficiencies of 14-28% [10]

Environmental Impact of Incineration

One problem associated is the potential for pollutants to enter the atmosphere with the flue gases from the boiler. These pollutants can be acidic and in the 1980s were reported to cause environmental degradation by turning rain into acid rain.

Although, in recent times, the use of lime scrubbers and electro-static precipitators on smokestacks is being used by the industry to tackle this problem. By passing the smoke through the basic lime scrubbers, any acids that might be in the smoke are neutralized which prevents the acid from reaching the atmosphere and hurting the environment. Many other devices, such as fabric filters, reactors, and catalysts destroy or capture other regulated pollutants [14].

Modern incineration plants are relatively clean and according to New York Times; "many times more dioxin is now released from home fireplaces and backyard barbecues than from incineration. [15]. Therefore, waste incineration plants are no longer significant in terms of emissions of dioxins, dust, and heavy metals due to stringent regulations and technological advancement in incineration WTE methods in most developed countries.

Pyrolysis

Pyrolysis, a word coined from the Greek-derived elements pyr 'fire' and lysis 'separating', is a thermal decomposition of organic material at elevated temperature in the absence of oxygen. Pyrolysis typically occurs under pressure and an operating temperature above 430°C (800°F). Pyrolysis of organic substances produces gas and liquid products and leaves a solid residue richer in carbon content. Pyrolysis differ from other high temperature processes like combustion and hydrolysis in that it does not involve reactions with oxygen, water or any other reagent. Although, in practice, it is not possible to achieve a completely oxygen-free atmosphere, which leads to a small amount of oxidation if volatile or semi-volatile materials are present in the waste which can also result to thermal desorption.

Pyrolysis is the basis of several methods that are being developed for producing fuel from biomass, which may include either crops grown for the purpose or biological waste products from other industries.

Although synthetic diesel fuel cannot yet be produced directly by pyrolysis of organic materials, there is

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a way to produce similar liquid (bio-oil) that can be used as fuel, after the removal of valuable bio-chemicals that can be used as food additives or pharmaceuticals. Higher efficiency is achieved by the so-called flash pyrolysis, in which finely divided feed stock is quickly heated to between 350°C and 500°C (600°F and 930°F).

Fuel bio-oil resembling light crude oil can also be produced by hydrous pyrolysis from many kinds of feedstock, including waste from pig and turkey farming, by a process called thermal de-polymerization (which may however include other reaction besides pyrolysis).

Anhydrous pyrolysis can thermo-chemically convert organic waste products into clean liquid fuels and can also be used to produce liquid fuel similar to diesel from plastic waste [9].

The Pyrolysis Process

The pyrolysis process consists of both simultaneous and successive reactions when carbon-rich organic material is heated in a non-reactive atmosphere. Simply speaking, pyrolysis is the thermal degradation of organic materials in the absence of oxygen. Thermal decomposition of organic components in the waste stream starts at 350°C–550°C and goes up to 700°C–800°C in the absence of air/oxygen.

Pyrolysis of municipal wastes begins with mechanical preparation and separation of glass, metals and inert materials prior to processing the remaining waste in a pyrolysis reactor. The commonly used pyrolysis reactors are rotary kilns, rotary hearth furnaces, and fluidized bed furnaces. The process requires an external heat source to maintain the high temperature required. Pyrolysis can be performed at relatively small-scale which may help in reducing transport and handling costs. In pyrolysis of MSW, heat transfer is a critical area as the process is endothermic and sufficient heat transfer surface has to be provided to meet the process heat requirements.

The process condition are altered to produce the desired char, gas or oil end product, with the pyrolysis temperature and heating rate having the most influence on the product distribution. The heat is supplied by indirect heating such as the combustion of the gases or oil, or directly by hot gas transfer. Pyrolysis process conditions can be optimized to produce either a solid char, gas or liquid/oil product [9].

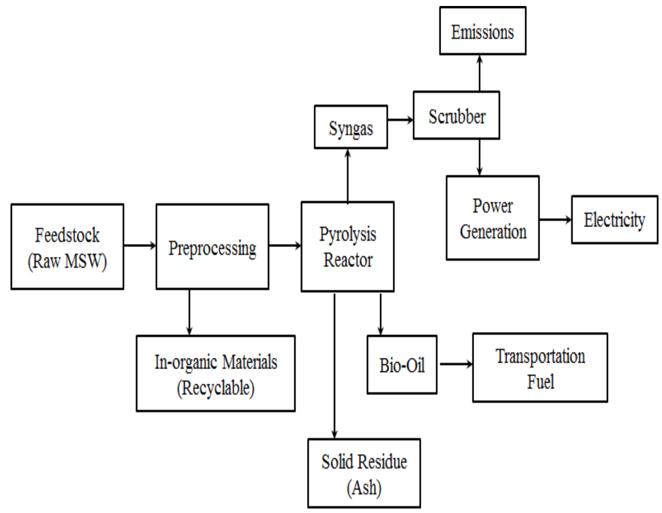

Fig 1: Pyrolysis Process Flow Diagram

Feedstock Sources: Many sources of organic matter can be used as feedstock for pyrolysis. Suitable plant material include green-waste, sawdust, waste wood, woody weeds, and agricultural sources including nut shells, straw, cotton trash, rice hulls, switch grass and animal waste including poultry litter, dairy manure and potentially other manure. Pyrolysis is used as a form of thermal treatment to reduce waste volumes of domestic refuse. Some industrial by-products are also suitable feedstock including paper sludge and distillers grain.

Benefits of Pyrolysis

One of the advantages of pyrolysis is that the gases or oil product derived from the waste can be used to provide fuel for the pyrolysis process itself. In addition, there is also the possibility of integrating with other processes such as mechanical biological treatment and anaerobic digestion.

The thermal treatment options of pyrolysis, gasification and combined pyrolysis/gasification systems are generating increasing interest as a viable alternative environmental and economic options for waste processing. These options have a number of advantages over conventional incineration or landfilling of waste.

Depending on the technology, the waste can be processed to produce not only energy, but also gas or oil products for use as petrochemical feedstock and /or a carbonaceous char for use in applications such as effluent treatment or gasification feedstock. The production of storable end products such as a gas, oil or char enables the possibility of decoupling the end use of the product, either for energy production or petrochemical use from the waste treatment process.

Limitations of Pyrolysis

Pyrolysis generates possible toxic residues such as inert mineral ash, inorganic compounds, and unreformed

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carbon and has potential to produce a number of possible toxic air emission such as acid gases, dioxins and furans, nitrogen oxides, sulfur dioxide, particulates, etc if the process is not properly carried out within the right parameters. More so, Pyrolysis plants require a certain amount of feedstock materials to work effectively [17].

Application of Pyrolysis

The main products obtained from pyrolysis of municipal wastes are a high calorific value gas (synthesis gas or syngas), a biofuel (bio oil or pyrolysis oil) and a solid residue (char). Depending on the final temperature, MSW pyrolysis will yield mainly solid residues at low temperatures, less than 450^0C, when the heating rate is quite slow, and mainly gases at high temperatures, greater than 800^0C, with rapid heating rates. At an intermediate temperature and under relatively high heating rates, the main product is a liquid fuel popularly known as bio oil [18].

Bio oil is a dark brown liquid which can be upgraded to either engine fuel or through gasification processes to a syngas and then biodiesel. Pyrolysis oil may also be used as liquid fuel for diesel engines and gas turbines to generate electricity Bio oil is particularly attractive for co-firing because it can be relatively easy to handle and burn than solid fuel and is cheaper to transport and store. In addition, bio oil is also a vital source for a wide range of organic compounds and specialty chemicals.

Syngas, another product from pyrolysis is a mixture of energy-rich gases (combustible constituents include carbon monoxide, hydrogen, methane and a broad range of other volatile organic compounds (VOCs)). The net calorific value (NCV) of syngas is between 10 and 20MJ/Nm^3. Syngas is cleaned to remove particulates, hydrocarbons, and soluble matter, and then combusted to generate electricity. Diesel engines, gas turbines, steam turbines and boilers can be used directly to generate electricity and heat in combined heat and power (CHP) systems using syngas and pyrolysis oil. Syngas may also be used as a basic chemical in petrochemical and refining industries.

The solid residue from MSW pyrolysis, called char, is a combination of non-combustible materials and carbon. Char is almost pure carbon and can be used in the manufacture of activated carbon filtration media (for water treatment applications) or as an agricultural soil amendment.

Environmental Impact of Pyrolysis

Pyrolysis is a rapidly developing biomass thermal conversion technology that is earning much attention worldwide due to its high efficiency and good eco-friendly performance characteristics.

The conversion of municipal solid wastes, scrap-tires, agricultural residues, non-recyclable plastics etc. into clean energy through pyrolysis technology has little or no negative impact on the environment. It offers an attractive way of converting urban wastes into products which can be effectively used for the production of heat, electricity and chemicals. However, if the process is not carefully handled, it can leave toxic residue and emit toxic substances into the atmosphere.

Thermal Depolymerization

Thermal depolymerization (TDP) is an industrial process of breaking down various waste materials into crude oil products. The materials are subjected to high temperatures and pressure in the presence of water, thereby initiating hydrous pyrolysis. As a result, the long chain polymers of the materials are depolymerized into short chain monomers. It is said to mimic the natural geological processes thought to be involved in fossil fuel production.

Thermal depolymerization occurs in nature when an accumulated biomass is heated and pressurized in the earth's crust over millions of years. This biomass, also known as kerogen, is believed to react with clay mineral enzymes at temperatures below 200°C (392°F), which produces oil. This method is rapidly gaining a lot of attention world-wide as an alternative source of energy. It is particularly helpful as solid wastes contain carbon, which can be chemically transformed into liquid fuel.

Thermal Depolymerization Process

In Thermal depolymerization process, the feedstock material is ground into tiny chunks and mixed with water. The mixture is then subjected to high pressure and heated at a constant volume to 250°C (482°F). This results to crude hydrocarbons and solid minerals being produced, which can be separated using fractional distillation and oil refining techniques. Some of the commonly used feedstock materials include corn, soya, sugarcane, tires, sewage sludge and medical wastes.

The following are the three main steps involved in the thermal depolymerization process:

- Feedstock is heated under pressure and pulped into a water slurry.
- Slurry is subjected to low pressure and then oil is separated from water.
- Crude oil is heated to high temperature to obtain light carbons in a solid form.

The temperature of the initial phase will be in the range of 200 to 300°C (392 to 572°F) and the next phase will be around 500°C (932°F).

Benefits of Thermal Depolymerization

Thermal depolymerization process can breakdown organic poisons by breaking the chemical bonds and deforming the molecular shape required for the poison's activity. It can also eliminate heavy metals from the samples by converting the metals from their ionized forms to stable oxides that can be separated from the other products.

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More so, TDP process recycles energy content of organic materials without removing the water. Unlike other recovering methods like pyrolysis and combustion, which require pre-drying or produces gaseous products, water is easily separated by liquid fuel in this method. Thus, simplifying the thermal conversion of waste to energy procedures.

In addition to reducing waste and by-products by using water as a medium, thermal depolymerization process also produces fuel resources that can benefit the world. This it does in an environmental friendly manner. .It also yields clean crude oil products by removing sulfur and nitrogen compounds.

Limitations of Thermal Depolymerization

Thermal depolymerization process only breaks long molecular chains into short chains. As a result, small molecules like methane or carbon dioxide cannot be converted into oil using this process. Hence, there is a need for additional refining steps. In addition, as the process requires temperature greater than 400°C (752°F), toxic byproducts like furan and dioxin may be released in addition to methane and carbon dioxide.

Applications of Thermal Depolymerization

Thermal depolymerization can treat a wide range of waste including biological, plastics, glass and needles, etc. It is a high heat process that involves physical and chemical changes. This results in total destruction of the waste, thus, bringing a significant reduction in the volume and mass of the waste. It is therefore an effective waste treatment and conversion process.

Thermal depolymerization WTE conversion method produces oil from agricultural plant wastes like hog manure, animal wastes, plastics, where the application of heat and pressure yields oil in addition to carbon dioxide, methane and water.

Environmental Impact of Thermal Depolymerization

TDP process of waste treatment and production of fuel products from organic waste and low quality feed stock has little or no negative impact on the environment.

Gasification

Gasification, unlike pyrolysis involves the reaction of oxygen in the form of air, steam or pure oxygen with the available carbon in the waste to produce ash and a tar product, at high temperature. Partial combustion occurs in the process to produce heat and the reaction proceeds exothermically to produce a low to medium caloric value fuel gas.

Bio-gasification (without heating of the waste) is another MSW gasification option. It is however considered less efficient than thermal MSW gasification.

Gasification of municipal wastes basically, involves the reaction of carbonaceous feedstock with an oxygen-containing reagent, usually oxygen, air, steam or carbon dioxide, generally at temperatures above 800°C. The process is largely exothermic but some heat may be required to initialise and sustain the gasification process. The main product of the gasification process is syngas, which contains carbon monoxide, hydrogen and methane.

Gasification Process

MSW gasification involves two processes, which must take place in order to produce a useable fuel gas [19]. First is through pyrolysis where the volatile components of the fuel are released at temperatures below 600°C. As a side benefit from this process, char is produced which consists mainly of fixed carbon and ash. At the second phase, the carbon remaining after pyrolysis is either reacted with steam or hydrogen or combusted with air or pure oxygen at temperatures between 760 and 1,650° C under high pressure.

Gasification with air results in a nitrogen-rich, low-Btu fuel gas, while gasification with pure oxygen results in a higher quality mixture of CO and hydrogen and virtually no nitrogen. Gasification with steam is generally called ‘reforming’ and results in a hydrogen- and CO_2-rich ‘synthetic’ gas (syngas). Cleaned from contaminants, the syngas can be combusted in a boiler, producing steam for power generation [20]

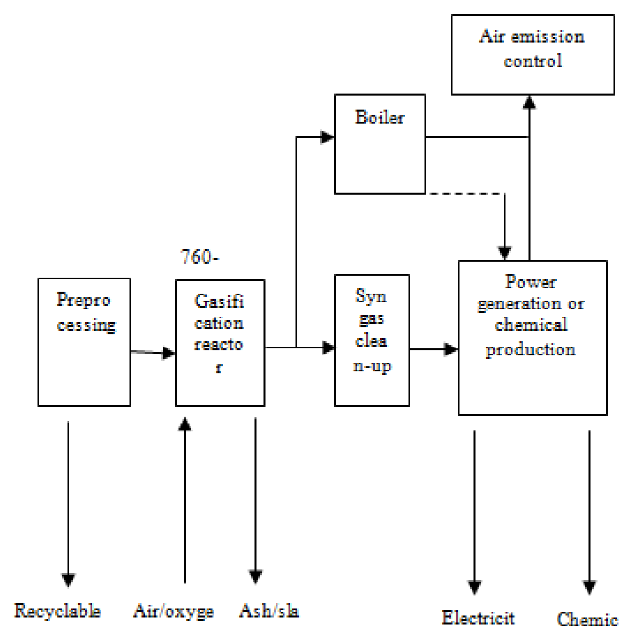

Fig 2: Process of MSW gasification

Feasibility of technology and operational necessities: Gasification is a more complex process than waste incineration, but the reactors used for both processes are quite similar. However, in contrast with waste incineration, the gasification technology reduces MSW into simpler molecules and substances like dioxins, and furans are generally destroyed [8]. The main reactor types are

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fixed beds and fluidised beds. Fixed-bed reactors typically have a grate to support the feed material and maintain a stationary reaction zone. They are relatively easy to design and operate and are therefore useful for small- and medium-scale power and thermal energy use. However, it is difficult to keep operating temperatures at constant levels and to ensure adequate gas mixing in the reaction zone. As a result, gas yields can be unpredictable and are not optimal for large-scale power purposes (i.e. over 1 MW) [19]. Therefore, larger capacity gasifiers are preferable for treatment of MSW because they allow for variable fuel feed, uniform process temperatures, good interaction between gases and solids, and high levels of carbon conversion.

Fluidised beds offer the best design for the (larger-scale) gasification of MSW. In a fluidised bed boiler, inert material and solid fuel are fluidised by means of air distributed below the bed. A stream of gas (typically air or steam) is passed upward through a bed of solid fuel and material (such as coarse sand or limestone). The gas acts as the fluidising medium and also provides the oxidant for combustion and tar cracking. The fluidised bed behaves like a boiling liquid and has some of the physical characteristics of a fluid. Waste is introduced either on top of the bed through a feed chute or into the bed through a so-called auger. Fluidised-beds have the advantage of extremely good mixing and high heat transfer, resulting in very uniform bed conditions and efficient reactions. Fluidised bed technology is more suitable for generators with capacities greater than 10 MW because it can be used with different fuels, requires relatively compact combustion chambers and allows for good operational control.

Benefits of Gasification

Gasification of solid wastes has several advantages over traditional combustion processes for MSW treatment. It takes place in a low oxygen environment that limits the formation of dioxins and of large quantities of SOx and NOx. Furthermore, it requires just a fraction of the stoichiometric amount of oxygen necessary for combustion. As a result, the volume of process gas is low, requiring smaller and less expensive gas cleaning equipment. The lower gas volume also means a higher partial pressure of contaminants in the off-gas, which favours more complete adsorption and particulate capture. Finally, gasification generates a fuel gas that can be integrated with combined cycle turbines, reciprocating engines and, potentially, with fuel cells that convert fuel energy to electricity more efficiently than conventional steam boilers. [13].

Limitation of Gasification

Gasification is a complex and sensitive process. Gasifiers require at least half an hour or more to start the process and frequent refueling is often required for continuous running of the system. Handling residues such as ash, tarry condensates is time consuming.

The gas resulting from gasification of municipal wastes contains various tars, particulates, halogens, heavy metals and alkaline compounds depending on the fuel composition and the particular gasification process which can cause environmental and operational problems. This can result in agglomeration in the gasification vessel, which can lead to clogging of fluidised beds and increased tar formation.

The key to achieving cost efficient, clean energy recovery from municipal solid waste gasification will be overcoming problems associated with the release and formation of these contaminants [13].

Application of Gasification

The chemical process of thermal gasification of municipal solid waste (MSW) generates a gaseous, fuel-rich product. This product can then be combusted in a boiler to produce steam for power generation.

The main product of the gasification process is a syngas, which contains carbon monoxide, hydrogen and methane. Typically, the gas generated from gasification has a low heating value (LHV) of 3 – 6 MJ/Nm^3. Syngas can be used in a number of ways, including;

- Being burned in a boiler to generate steam for power generation or industrial heating.
- It can be used as fuel in a dedicated gas engine.
- After reforming, syngas can be used in a gas turbine. Syngas can also be used as a chemical feedstock.

The other main product produced by gasification is a solid residue of non-combustible materials (ash) which contains a relatively low level of carbon.

Environmental Impact of Gasification

The environmental problems associated with Gasification facilities are similar to those associated with mass burn incinerators which may include water pollution, air pollution, disposal of ash and other by-products. Gasification process involves huge amounts of water for cooling purposes [24].

Anaerobic Digestion

Anaerobic digestion (AD) is another example of WTE. It is an old but effective technology that biologically converts organic material into compost as well as biogas for energy [21]. AD systems have large potential and can range from low to high technology, therefore they can service communities of all income levels.

Biogas is a gaseous fuel obtained from biomass by the process of anaerobic digestion. The in-feed to the biogas plant includes but not limited to; Urban waste (Garbage), Urban refuse (Human excreta), Rural & agricultural waste, Cow-dung and Animal waste from butchery.

Biogas is a cheap secondary renewable energy. The in-feed to the biogas plant is mixed with water to assist anaerobic fermentation. The biogas plant delivers methane

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rich gas which has Methane CH4, Carbon-dioxide (CO2) and other impurities

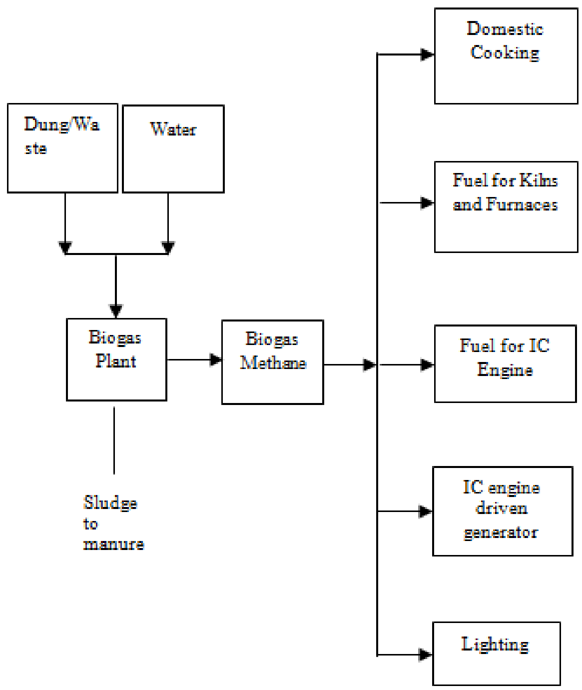

Fig 3: Anaerobic Digestion Process Flow Diagram

Anaerobic digestion process

Anaerobic digestion process is a type of biochemical conversion involving microbial digestion of biomass. The process and end product depend upon the micro-organism cultivated and the culture condition.

An anaerobe is a microscopic organism that lives and grows without external oxygen or air. It extracts oxygen by decomposing the biomass at low temperature up to 65°C in presence of moisture (80%) at atmospheric pressure. Anaerobic digestion of biomass generates mostly methane and Carbon dioxide gas with small impurities such as hydrogen sulfide. The output gas obtained from anaerobic digestion can be directly burned or upgraded to superior fuel gas (methane) by removal of CO2 and other impurities [6].

The Anaerobic digestion process has three phases

1. Enzymatic hydrolysis of biomass**:** This involves the breakdown of the original organic matter containing carbohydrates, fats and complex organic matter into simpler organic compounds.

2. Formation of acids and chemicals**:** The anaerobic micro-organisms and facultative groups produce fermentation and hydrolysis to form acids, volatile liquid and solid of simpler organic nature like aldehydes, alcohol, acids, acetates formats etc. Care should be taken at this stage to avoid the production of excess acid which can retard the process. During the initial acid formation of about two weeks, substantial amount of carbon dioxide is released.

3. Production of methane (CH4): in this stage, the organic acids and chemicals formed in the second stage are decomposed by anaerobes to release methane (CH4) and carbon dioxide gases. This process is called methane fermentation.

The acid forming bacteria are different from the methane forming bacteria. In a well-designed biogas plant and controlled digestion process, the growth of both types of bacteria are self-sustaining and continuous if the following parameters are controlled during the anaerobic digestion;

- Population of micro-organism of both types
- Food supply (feed of biomassand water)
- Temperature (30°C to 60°C)
- Food (Slurry) mixing and agitation
- pH value
- Pressure
- Type of feeding and feeding rate
- Fermentation agent

The Biogas Plant

The plant that converts biomass to biogas (methane plus carbon dioxide) by the process of anaerobic digestion is referred to as Biogas Plant.

The feed slurry is fed to the Digester (Reactor) directly or through an inlet Tank. Seeding matter (bacteria rich substance) may be added to the slurry in the digester to start and accelerate the process of anaerobic digestion.

The slurry is retained in the digester for several days, (30-60 days) to allow anaerobic fermentation. This time period is called retention time which varies with certain factors like size of biogas plant, type of in-feed, rate of in-feed, ambient temperature etc.

The temperature is kept between 25c to 63c. The biogas is obtained from the outlet pipe on the digester [6].

Types of Biogas Plant

Biogas plants are built in several different configuration; simple to complex. The common types of biogas plants are

- Continuous type
- Batch type
- Fixed collector
- Floating dome collector type [6]

Benefits of Anaerobic Digestion

The following are benefits of AD

- Can process a variety of biomass materials
- Produces practical by-products which can easily be captured and used for soil fertilization and the generation of heat and/or electricity
- Produces the least amount of air and solid emissions in comparison to typical waste

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management processes such as incineration, pyrolysis and gasification;
- AD plants can be small and unobtrusive, which makes them suitable for locations within towns.
- Digestion of sewage waste via AD results in 10% reduction in carbon dioxide emissions
- AD with combined heat and power (CHP) systems produces net reductions in pollutant emissions.

Limitation of Anaerobic Digestion

The following are some limitations associated with Anaerobic Digestion process;

- If AD does not completely digest all the waste, the resulting digestate may not meet Government standards.
- Poor feedstock used in the AD process can result in the production of unusable by-products. Depending on the feedstock, AD may create contaminated digestates that are high in metals such as mercury.
- Combustion of biogas produces nitrogen oxides, which are associated with lung problems and allergies
- Biogas is composed of methane and carbon dioxide which are toxic greenhouse gases associated with climate change, if released into the atmosphere.
- AD plants generate lots of waste water high in nitrites.
- AD plants may cause environmental problems such as odour, dust and pollutants due to the burning of methane for power generation.

Application of Anaerobic Digestion

Biogas plant has a significant role to play in community development and energy strategy for developing countries. The fuel used for biogas plant is derived from renewable animal and agricultural waste.

The raw biogas obtained from the biogas plant by the process of anaerobic digestion is a methane rich fuel gas with the following composition:

- Methane (CH_4) - 55 to 60%
- Carbon dioxide (CO_2) -36 to 40%
- Hydrogen (H_2) – 5%
- H_2S and O_2 – Traces

The biogas produced by the biogas plant is used for the following

- Domestic fuel for burners used in kitchen (cooking). Fuel for internal combustion (IC) engine to drive pump sets, producing electrical energy from IC Engine Driven Generator Sets.
- Fuel for IC engine driven generating plants for supplying electrical energy to the community
- Fuel for kiln, furnaces.
- Residue from the biogas plant is used as manure
- Energy conservation of fossil fuel and electrical energy from conventional power plants
- Use of biogas can aid the conservation of trees and plants which will otherwise be used as fuel if biogas is not available

Biogas is emerging as a principal renewable energy form for villages and communities

Environmental Impact of Anaerobic Digestion

In comparison to the other WTE technologies like incineration, pyrolysis, gasification and landfill, anaerobic digestion produces less air and solid emissions than the others [22]. This is due to the enclosed nature of the process. The gas produced as a result of anaerobic digestion is contained within gas holders located above the secondary digesters and the digestate storage tanks which can be pumped directly into a Combined Heat and Power (CHP) unit which then converts the gas into electricity and heat. Therefore, no gases from the anaerobic digestion process would be released into the environment (Green for Life Energy: 2014).

The feedstock for AD is treated within a fully enclosed oxygen-free environment to mitigate the impact of odour to the environment

Landfill Gas Recovery

A landfill is an engineered method for land disposal of solid or hazardous waste in a manner that protects the environment. Within the landfill, biological, chemical, and physical processes occur that promote the degradation of waste and result in the production of leachate (polluted water emanating from the base of the land fill) and gases [4].

Landfill Gas Recovery Process

Landfill gas recovery refers to the process of capturing the gases emitted from municipal landfills and converting it for energy. The most common form of collection occurs by drilling horizontal or vertical wells into the landfill and using blowers and vacuums to collect the gas for treatment.

In some developed countries, most waste is incinerated or composted or undergo Mechanical-Biological Treatment (MBT) prior to landfilling while some operate a landfill as a bioreactor. The bioreactor landfill provides control and process optimization, primarily through the addition of leachate or other liquid amendments, if necessary. Bioreactors may involve addition of waste water sludge and other amendments, temperature control, and nutrient supplementation. The bioreactor attempts to control, monitor, and optimize the waste stabilization process.

Gas is extracted by placing gas collectors into landfills when it is being constructed or by drilling wells into completed landfills. The design for methane extraction from landfills involve the proper spacing of wells, the type of wells, and the gas cleaning or processing facility. Wells

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can be either vertical or horizontal, depending on the need. Typically, a 0.3- to 1.0-m diameter auger is used to drill the well, and a 10- to 15-cm PVC (polyvinyl chloride) pipe is placed inside the well with the remaining space filled with gravel.

Benefits of Landfill Gas Recovery

***Reduction of greenhouse gas emissions*:** Given that all landfills generate methane, it makes sense to use the gas for the beneficial purpose of energy generation rather than emitting it to the atmosphere.

Create Health and Safety Benefits: Burning LFG to produce electricity destroys most of the non-methane organic compounds (including hazardous air pollutants and Volatile organic compounds (VOCs)) that are present at low concentrations in uncontrolled LFG, which reduces possible health risks from these compounds. In addition, gas collection can improve safety by reducing explosion hazards from gas accumulation in structures on or near the landfill. *Economic Benefits:* Generating electricity from existing MSW landfills is also a relatively cost-effective way to provide new renewable energy generation capacity to supply community power needs. LFG energy projects generate revenue from the sale of the gas. LFG use can also create jobs associated with the design, construction, and operation of energy recovery systems which is beneficial to the community and economy.

Limitation of Landfill Gas Recovery

The following are some limitations associated with energy recovery from landfills;

- Landfills are an unsustainable use of land and pose environmental concerns including water and air quality issues.
- Recycling reduces landfill available for sufficient gas recovery
- When gas is exhausted, the generation site must be relocated
- Much larger volumes of landfill are required for the same amount of electricity produced by fossil fuels

Application of Methane Extraction from Landfills

Landfill gas is currently being used in several ways. Some landfills use landfill gas to generate electricity by burning the gas in an internal combustion engine and direct-coupling this to a generator. Electricity can also be generated using a turbine or a gas-fired boiler with generator.

Landfill gas can also be sold as fuel for others to use and exported. For example, a land fill near an oil field exports its landfill gas to the exploration company. The company uses the landfill gas to generate steam which is injected into the oil filed as a way of increasing yield.

Environmental Impact of Landfill Gas Recovery

Landfilling with energy recovery has a slightly lower environmental impact than the landfilling without energy recovery in that the gas is collected. However, an important factor to consider in the selection of the site where a landfill will be constructed is that the area where the solid wastes will be accumulated must be away from inhabited and environmentally protected areas because it can constitute nuisance to communities.

IV. CONCLUSION

The most significant challenge to WTE technology adoption is the awareness that waste can be used as an alternative source of energy.

Proper waste management and control constitutes one of the major challenges faced by developing nations. Litters of waste on the roads and water bodies are a common site in these parts of the world leading to environmental pollution (land, water and air). The common waste management method employed is open air combustion of waste which releases harmful substances to the atmosphere that pose as threat to humans and the environment. Some of the technologies employed by developed nations to manage waste and convert them to useful products like energy can be employed in developing nations with potential benefits to the economies and the environment.

Developing countries can take a cue from countries where waste is being utilized as energy resources and other uses.

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