A RELATIVE STUDY ON THE MOST EFFECTIVE METHOD OF SOLID WASTE DISPOSAL TECHNIQUES (AN OVERVIEW OF BIOLOGICAL, THERMAL AND PHYSICAL TREATMENTS TECHNOLOGIES)

Murtala Hassan Mohammed*[1],
Aliyu Baba[2],
Kachallah Alhaji Kau[3]
*[123]Modibbo Adama University of Technology, Yola, Adamawa State, Nigeria

ABSTRACT
This research focused on three methods of Solid Waste Disposals thus; Biological, Thermal and Physical technologies. Thermal treatment (Open burning), this uncontrolled burning of garbage releases many pollutants into the atmosphere which have many negative effects on both human health and the environment. These include dioxins, particulate matter, polycyclic aromatic compounds, volatile organic compounds, carbon monoxide, hexachlorobenzene and ash. All of these chemicals pose serious risks to human health. Biological treatment will require longer time than thermal conversion as biological processes takes days, weeks or even months to be carried out fully. These processes may be particularly suited for some MSW fractions i.e. niche applications and will therefore contribute to the expansion of the MSW treatment arsenal. Physical treatment (Landfilling), involve placing solid and semi solid wastes on the ground, compacting and converting it with suitable materials to isolate it from the environment. It is still one of the most common and favoured methods for solid waste disposal.

Keywords:
Municipal Solid Waste, Biological Treatment, Thermal Treatment, Physical Treatment.

INTRODUCTION

Solid waste is the unwanted or useless solid materials generated from combined residential, industrial and commercial activities in a given area. It may be categorised according to its origin (domestic, industrial, commercial, construction or institutional); according to its contents (organic material, glass, metal, plastic paper etc); or according to hazard potential (toxic, non-toxin, flammable, radioactive, infectious etc).

According to (Zaman, 2000) waste is no more treated as the valueless garbage; waste is rather considered as a resource in the present time. Resource recovery is one of the prime objectives in sustainable waste management system. Different waste treatment options are available in the current time with different waste management capacities. There is no a single technology that can solve the waste management problem (Tehrani et al, 2009). Integrated waste management system is commonly applied method in many developed countries. Integrated waste management system offers the flexibility of waste treatment option based on different waste fraction like plastic, glass, organic waste or combustible waste. Energy and resource recovery is also important and can be recovered through integrated waste management system. There are different system analysis tools (Finnveden & Moberg, 2004) that are available at the present time for the decision makers. Technology or strategy can be analyzed by the environmental, social or environmental point of view. Different studies have already been done for MSW management options to analyze the benefits and problems associated with the processes. Some of the studies are done by (Consonni et al, 2005).

SOURCES OF SOLID WASTE

There are six general sources of waste generation, namely; domestic, commercial, industrial, agricultural, institutional and natural:

The characteristics of solid waste from each of these sources vary widely. The proportion of these components is dependent on various other factors.

- Households are the highest producers of domestic waste. Domestic waste includes, among others, paper and cartons, plastics, glass, leftover food, cans.
- The main agents of commercial waste producers are stores, business premises, markets and restaurants.
- Industrial waste refers to wastes such as construction and demolition debris and food processing outlets.

- Agricultural wastes refer to the waste outcomes from dairy and poultry farms, livestock and other agricultural activities like vegetation cultivation. Most of the agricultural wastes contain biodegradable components.
- In case of institutional wastes, major producers are schools, offices and banks. This type of waste contains paper and cartons.
  A. Natural waste consists of leaves, tree branches, seeds and carcasses of animals.

MUNICIPAL SOLID WASTE

Municipal solid waste (MSW) includes refuse from households, non-hazardous solid waste from industrial, commercial and institutional establishments (including hospitals), market waste, yard waste and street sweepings. MSWM refers to the collection, transfer, treatment, recycling, resources recovery and disposal of solid waste in urban areas. The goals of municipal solid waste management are to promote the quality of the urban environment, generate employment and income, and protect human and environmental health and support the efficiency and productivity of the economy (Ogwueleka, 2009). (Igoni et al, 2007) Defined MSW as all waste collected by private and public authorities from domestic, commercial and some industrial (non-hazardous) sources. Urban solid waste is a heterogeneous material and its generation rate and composition vary from place to place and from season to season (World Resources Institute, 1996); (Gidarakos, 2006). The composition and volumes differ between high and low-income locations (UNEP, 2000). According to (Ogwueleka, 2009), solid waste is wetter, heavier and more corrosive in developing nations, making its management more difficult.

INTEGRATED SOLID WASTE MANAGEMENT

Integrated Solid Waste Management (ISWM) takes an overall approach to creating sustainable systems that are economically affordable, socially acceptable and environmentally effective. An integrated solid waste management system involves the use of a range of different treatment methods, and key to the functioning of such a system is the collection and sorting of the waste. It is important to note that no one single treatment method can manage all the waste materials in an environmentally effective way. Thus all of the available treatment and disposal options must be evaluated equally and the best combination of the available options suited to the particular community chosen. Effective management schemes therefore need to operate in ways which best meet current social, economic, and environmental conditions of the municipality.

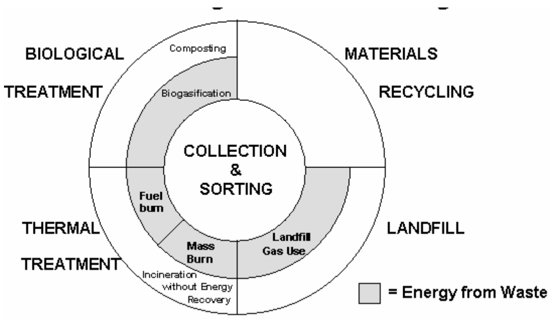


Figure 1: Elements of Integrated Solid Waste Management (http://viso.ei.jrc.it/iwmlca)

METHODOLOGY

The methodology adopted in this paper is an intensive literature review on the various types of technologies for solid waste disposal.

BIOLOGICAL WASTE TREATMENT

The biological waste treatment include: Composting, Aerated static pile, In-vessel, Windrow, Fermentation.

COMPOSTING

Scientific literatures define composting as the natural break down of organic solid materials into a component of soil comparable substance called compost. This breaks down supports the postulations of individual scholars that nature composting process provides fertilizers for healthy plants (Bertoldi, 1996). Humans thereby replicated the process by placing pile of organic solid waste on the topsoil or in a silo for microbes to degrade while synthesising their own food (McNelly, 2009); (Pommier et al, 2008). Composting process for organic solid materials occurs under the influence of micro and macro organisms such as actinomycetes, fungi, bacteria, mites and snails (ACES, 2000). Some of the organic solid materials to compost include cardboard rolls, news papers, fruits, vegetables, yard trims, sawdust, and coffee husks, and straws (USEPA, 2000).

In traditional composting systems, organic material is just piled together and then left for a year; while more elaborated composting systems take 2 to 3 weeks for complete decomposition. This system necessitates that the materials to compost be chopped up, into small pieces, and carbon (C) to nitrogen (N) ratio not exceeding 30:1. It also requires moisture content in the compost between 40 to 60%, achieved by adding in water during construction and turning of the compost pile. Effective composting needs to take place at the temperature range of 30-70o C, and regular turning of the compost pile to prevent overheat that would kill microbes (Raabe & Robert, 2001).

Another important factor to achieve rapid composting, which (Raabe & Robert, 2001) warned for, is to avoid adding more organic materials into the bin once the composting process is in progress. The reason is that the effective breakdown of materials takes place within a fixed period. He also discouraged the adding of materials, for instance soil and ashes from the fireplace or cooking stoves, into the bin. These materials add weight to the compost pile, thus making the turning of the solid waste pile more strenuous. Ashes may also influence the power of hydrogen (pH). The effective composting system requires effective environmental conditions to help microbes break down organic materials (Fig. 2). The three significant factors, which determine these conditions, include; (a) quality and quantity of carbon (food) as an energy source and a source of minerals (b) shape and physical dimensions of the organic ingredients; (c) the appropriate population of organisms engaged in the decomposition of organic solid materials into substantial manure (Cooperband, 2000).

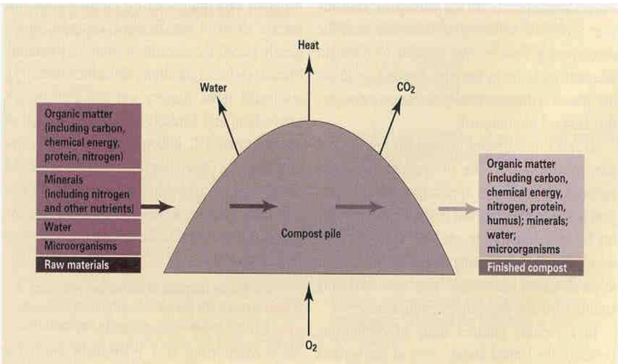


Figure 2: Schematic of the Composting Process for Raw Organic Materials into Finished Compost (Ebeling, 2003)

The effective composting system, often performed by microbes, occurs within the recommendable carbon to nitrogen ratio in waste materials. The recommendable mass ratio of carbon to nitrogen is: 30:1. This ratio enables microbes to speed up the decomposition process. The carbon to nitrogen ratio (Table 1) helps to avoid the lengthy decay in case of excess carbon. The ratio also prevents foul smell from the compost pile, which occurs when nitrogen content is too high (Ebeling, 2003).

Table 1: Estimated Carbon and Nitrogen Content of Some Organic Materials (Ebeling, 2003); (DNREC, 2007)

Materials with High Nitrogen Values	
Materials	**C:N ratio**
Vegetable waste	12-20:1
Coffee grounds	20:1
Grass clippings	12-25:1
Cow manure	20:1
Horse manure	25:1
Horse manure w/ Litter	30-60:1
Poultry manure (Fresh)	10:1
Poultry manure (w/ Litter)	13-18:1
Pig manure	5-7:1
Materials with High Carbon Values	
Materials	**C:N ratio**
Foliage (Leaves)	30-80;1
Corn stalks	60:1
Straw	40-100:1
Bark	100-130:1
Papers	150-200:1
Wood chips and sawdust	100-500:1

Balancing carbon-to-nitrogen ratio requires proper identification of common organic materials, with high concentration of carbon, are brown in colour. Those with high concentration of nitrogen contain green colour. The moisture content of organic materials is also critical. Leaves and sawdust have 40%, fruits and vegetables 80 to 90%, grass clippings 80%, and shrub trims 15% (Trautmann & Krasny, 1997). The aerobic composting system requires oxygen to produce carbon dioxide, nitrogen, water and heat needed by microbes (USEPA, 2000); Bruce, 2000). The process is a significant factor of the natural reduction of pollutants at various dump sites of organic solid waste. It enables the rapid break down of oxygen demanding organic solid materials by microbes to produce odour and leachate, and compost at the final stage (Sarika, 2007).

AN AERATED STATIC PILE

This method uses positive pressure aeration based on what (Sesay et al, 1998) described as temperature feedback control. It mixes organic solid materials together in one large pile. This method is suitable for a relatively homogenous organic solid waste mixed together and covered under a shelter. Aerated static pile is suitable especially in the arid climate, to avoid possible evaporation. It requires careful monitoring to make sure that the heat inside the compost pile is more than heat outside layer of the pile. More internal heat reduces odours with the support of applied thick layer, with about 15cm, of finished compost over the stack. This maintains high temperatures all (Diaz et al2007).

IN-VESSEL

This is a composting method where the decomposition of organic solid materials happens within an enclosed drum, silo, or vessel. This enables the operator to maintain a closer control of the process (USEPA, 2000). It has the advantage of operating at most favourable temperature conditions and moisture content. In-vessel facilitates composting of a wider range of organic materials; it captures and treats odours from the composting process

WINDROW

This is also a composting method which places the mixed organic solid waste in long, tapered piles turned on a regular basis. The turning process mixes the composting materials and increases passive aeration. The efficiency turning of organic solid materials within windrow depends on the equipment used, which also determines the shape, size and its spacing. The windrow's size that can be effectively aerated depends on quality of many small holes on it. The holes allow water to pass through slowly (Misra, 2003).

FERMENTATION

Fermentation is of interest for the biomass fraction of MSW and more generally biomass residues. This process includes two steps: (1) lignocellulosic materials are first hydrolysed to sugars with the help of enzyme and/or acid hydrolysis (Xiang et al, 2003) and thereafter (2) converted into ethanol through fermentation. Ethanol production from lignocellulosic materials (not only corn but woody biomass) is a hot topic as development of a car fuel blend including 85% of ethanol and 15% gasoline known as E85 is a serious alternative to conventional gasoline. The trend now is for the production of Flexible Fuel Vehicles that can function either on gasoline or on E85. An overview of ethanol production (potentials, constraints and technologies) from waste and biomass residues can be found in (Prasad et al, 2006).

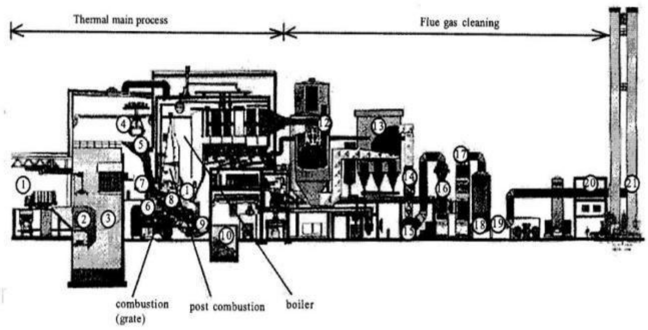
THERMAL TREATMENT

This refers to processes that involve the use of heat to treat waste. Listed below are descriptions of some commonly utilized thermal treatment processes

INCINERATION

Incineration is the most common thermal treatment process. This is the combustion of waste in the presence of oxygen. After incineration, the wastes are converted to carbon dioxide, water vapour and ash. This method may be used as a means of recovering energy to be used in heating or the supply of electricity. In addition to supplying energy incineration technologies have the advantage of reducing the volume of the waste, rendering it harmless, reducing transportation costs and reducing the production of the green house gas methane.

Waste is combusted in the temperature of 850ºC and in this stage waste converted to carbon dioxide, water and non-combustible materials with solid residue state called incinerator bottom ash (IBA) that always contains a small amount of residual carbon (DEFRA, 2007).



1- Delivery 2- Bulky refuse crusher 3- Waste bunker 4- Grab crane 5- Changing hopper 6- Reverse acting grate 7- Changing equipment 8- Primary air 9- Ash discharge (wet) 10- Ash bunker 11- Secondary air 12- Spray absorber 13- Fabric filter 14- Sound absorber 15- Induced draught-boiler 16- Venturi-scrubber 17- Radial flow-scrubber 18- Wet-electric filter 19- Clean gas reheating 20- Analytical room 21- Chimney

Figure 3: A schematic MSW Combustion Plant (Zaman, 2000); (Ludwing et al, 2003).

Fig. 3, shows the schematic diagram of MSW combustion plant where wastes are delivered as feed stock to the pre-combustion (grate) and during post combustion, gas and slug or ashes are produced. Then, in the next phases flue gas is cleaned by water absorber or different filtering methods. Finally, the clean gas is emitted through the chimney to the air. Thermal conversation of waste to energy is now very much applied technology for waste management system due to the generation of heat and energy from the waste stream. This treatment is a chemical process in which solid waste is, however, converted into residues which require landfill for final disposal (Mishra, 2008).

Countries such as Germany, Sweden, Italy, Switzerland, Luxembourg, Netherlands, and Japan incinerate more than 50% of their municipal solid waste. These countries build their incineration plants with treatment facility for the flue gases. These plants have two main components; rotary kiln combustion chamber for solid and liquid waste, and afterburners chambers that destroy materials not burnt in the initial process. Besides, ash residues collected in a large container, from the rotary kiln, can be tested to identify harmful material concentration levels prior to landfill disposal, or before being used in construction (Baskar & Baskar, 2007).

The air pollution control devices/systems enable the detoxification of toxic organic waste that would cause environmental health threats. They thereby reduce impact of CO_2, though it will come out in any case, and CH_4 from the landfills, which are more than that of other greenhouse gases generated from incinerator plants

(Niessen, 2002). Therefore, incineration process causes less global warming than open landfill disposal; landfill generates CH_4 with global warming potential of 21 tons in the timeframe of 100 years (Bracmort et al, 2011).

PYROLYSIS/GASIFICATION

Pyrolysis is the thermal degradation of waste in the absence of air to produce gas (often termed syngas), liquid (pyrolysis oil) or solid (char, mainly ash and carbon). These techniques use heat and an oxygen starved environment to convert biomass into other forms. A mixture of combustible and non-combustible gases as well as pyroligenous liquid is produced by these processes. All of these products have a high heat value and can be utilized. Gasification is advantageous since it allows for the incineration of waste with energy recovery and without the air pollution that is characteristic of other incineration methods (DEQ, 2006). MSW pyrolysis and in particular gasification is obviously very attractive to reduce and avoid corrosion and emissions by retaining alkali and heavy metals (Malkow, 2004). There would be a net reduction in the emission of the sulphur dioxide and particulates from the Pyrolysis/Gasification processes. However, the emission of oxides of nitrogen, VOCs and dioxins might be similar with the other thermal waste treatment technology (DEFRA, 2004).

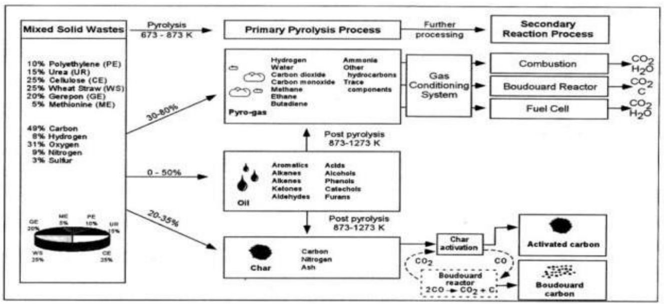


Figure 4: The Pyrolysis Processing Scheme for Solid Waste Proposed by AFR (Michael et al, 2008)

Pyrolysis produces energy carriers in three forms: bio-oil (liquid), charcoal (solid) and gas. The potential utilisations of those products are diverse.

The **Bio-oil**, composed of aliphatic and aromatic hydrocarbons along with more than 200 identified compounds (González et al, 2003), is a very flexible energy carrier. It can be transported and stored for use in energy and heat generation in boilers as a fuel-oil substitute (or in co-firing) and has the potential to be employed as a liquid transportation fuel for internal combustion engines. However, several properties (see Table 2) of the bio-oils such as high water content, low pH, high viscosity, corrosiveness, poor ignition ability and instability due to the oxygen content have to be ameliorated or existing equipment have to be modified to meet competitive standards (González et al, 2003) ; (Encinar et al, 1996); (Czernik & Bridgewater, 2004).

Table 2: Properties of Bio oil and Diesel oil (González et al, 2003)

	Bio-oil from wood [39]	Bio oil from wood [42]	Diesel no. 2 [39]
Moisture Content	17.0-19=8.9	15 – 30	N. A
pH	2.4 – 2.8	2.5	1
Specific Gravity	1.20 – 1.25	1.20	0.847
Elemental Analysis C (wt%)	44.0 – 46.5	55 – 58	86
H	6.9 – 7.2	5.5 – 7.0	11.1
O	46.1 – 49.0	35 – 40	0
N	N.A	0.0 – 0.2	1
S	N.A	N.A	0.8
HHV (MJ/kg) as produces	10.0 -3.9	16 – 19	44.7
Viscosity	13.5-28 cSt (50^0C)	40-100 cp (40^0C, 25% H_2O)	Less 2.39 (50^0C)

The establishment of standards for the specification of bio-oil is an important step for its commercialisation. Upgrading of the bio-oil can be done by different means (Oasmaa & Czernik, 1999), deoxygenation (by high-pressure hydrogenation in the presence of metal catalysts for example) to increase the heating value, hot vapour filtration to remove char, solvent addition to homogenise and reduce viscosity, use of surfactants to allow bio-oil/hydrocarbon fuel emulsification, novel concepts to improve bio-oil characteristics such as catalytic conversion, with the help of mesoporous materials (Adam, 2005).

OPEN BURNING

Open burning is the burning of unwanted materials in a manner that causes smoke and other emissions to be released directly into the air without passing through a chimney or stack. This includes the burning of outdoor piles, burning in a burn barrel and the use of incinerators which have no pollution control devices and as such release the gaseous by products directly into the atmosphere. Open burning has been practiced by a number of urban centres because it reduces the volume of refuse received at the dump and therefore extends the life of their dumpsite. Garbage may be burnt because of the ease and convenience of the method or because of the cheapness of the method. In countries where house holders are required to pay for garbage disposal, burning of waste in the backyard allows the householder to avoid paying the costs associated with collecting, hauling and dumping the waste (DEQ, 2006).

However, (DEQ, 2006) stated that harmful effects of open burning are also felt by the environment. This process releases acidic gases such as the halo-hydrides; it also may release the oxides of nitrogen and carbon. Nitrogen oxides contribute to acid rain, ozone depletion, smog and global warming. In addition to being a green house gas carbon monoxide reacts with sunlight to produce ozone which can be harmful. The particulate matter creates smoke and haze which contribute to air pollution.

PHYSICAL WASTE TREATMENT

According to (DEQ, 2006) efficient and responsible waste management strategies include several physical treatments as follows:

SOURCE REDUCTION

The **Source Reduction** is a pre-emptive measure aimed at lowering the amount of waste. This could be achieved by adopting various measures such as design of smaller, biodegradable packages, purchase of bulk products, reduce use of disposable items or lengthening the life of durable goods (less renewal, charities). Industrials and consumers can both act towards this goal but political involvement can fasten and improve the results.

SEPARATION

The separation consists of removing some fractions, especially problematic fractions (PVC, batteries, etc) in order to provide proper handling of these but also to prevent problems associated with them. For example, removal of PVC from MSW mainstream will greatly reduces production of Cl-containing compounds during combustion.

RECYCLING

Recycling is an important feature of waste management as it is a step towards a more sustainable society. Recycling consists in the re-use, after proper re-processing, of materials. Recycling allows a reduced use of natural resources and offers commercially viable opportunities. Recycling is mostly aimed at paper products, plastic, metal and glass but may apply to other products.

LANDFILL

"A landfill is a facility in which solid wastes are disposed in a manner which limits their impact on the environment. Landfills consist of a complex system of interrelated components and sub-systems that act together to break down and stabilize disposed wastes over time" (FCM, 2004). Landfill is very old but still one of the extensively used technologies for MWS management. Most of the landfill does not have the energy production facilities. In this study, a sanitary landfill with energy recovery system has been studied. Landfill gas are generated from the landfill site in different gas generation phases. Generally, five different phases like initial adjustment, transition phase, acid phase, methane fermentation and maturation phases are observed in waste landfill (Farquhar & Rovers, 1973) ; (Parker, 1983) ; (Pohland, 1991). A typical WTE generation by landfill process has shown in Fig. 5.

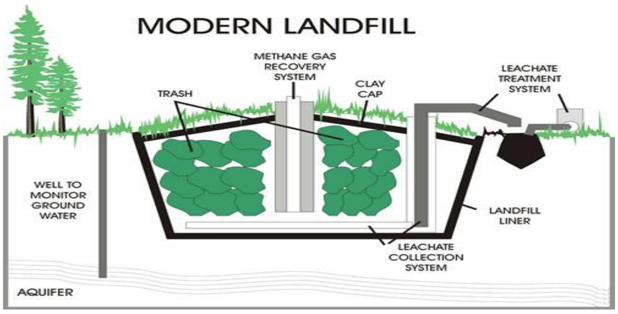


Figure 5: Main Features of a Modern Landfill (DEQ, 2006);
(http://www.eia.doe.gov/kids/energyfacts/saving/recycling/solidwaste/landfiller.html)

SANITARY LANDFILLS

Sanitary Landfills are designed to greatly reduce or eliminate the risks that waste disposal may pose to the public health and environmental quality. They are usually placed in areas where land features act as natural buffers between the landfill and the environment. For example the area may be comprised of clay soil which is fairly impermeable due to its tightly packed particles, or the area may be characterised by a low water table and an absence of surface water bodies thus preventing the threat of water contamination. Some sanitary landfills are used to recover energy. The natural anaerobic decomposition of the waste in the landfill produces landfill gases which include Carbon Dioxide, methane and traces of other gases. Methane can be used as an energy source to produce heat or electricity. Thus some landfills are fitted with landfill
gas collection (LFG) systems to capitalise on the methane being produced. The process of generating gas is very slow, for the energy recovery system to be successful there needs to be large volumes of wastes (DEQ, 2006).

BRIQUETTING

It is the conversion of organic solid materials, through different processes including hydraulic pressing, piston and screw pressing, into solid fuel. Several scientific descriptions about briquetting system stretch from resource exploitation, to the invention of technologies to cut back further human depletion of natural resources (Demirbas, 2010). The Shree Khodiyar Engineering Works (unpublished observations) warned that the reliance of human beings, for survival, to natural resources is irreversible. Several scientific studies have also invented technologies to overcome depletion of natural resources for energy generation. These technologies transform organic solid waste into raw materials for heat production. The invention of such technologies led to the development of briquetting theory (Filho & Butorina, 2002).

Briquetting is used in emerging economies in the solid waste management. It may incorporate both raw material recovery and environmentally sound handling of organic solid waste (Koufodimos & Samaras, 2002). Since 1990, organic solid waste became the leading source of solid fuel worldwide. Countries such as Germany and Netherlands have realised contribution of briquetting organic solid waste for heat production (Bautista & Pereira, 2006). These countries transform different organic solid waste including cardboard, sawdust, shavings, waste papers, yard trims, and other assorted municipal solid waste into pellets or briquettes for heat production (Plistil et al, 2005).

Transforming organic solid materials into solid fuel requires starch or a binder for sticking flaked materials together to produce a pellet or briquette. The next step is to dry it to increase its physical strength. The drying of a pellet or briquette is at about 80oC in a furnace or the sun ((FAO, 1987). It is usually prepared by passing on hot air to reduce moisture content from 25% to 10% (Li Yadong, 2000).

There are three different methods (roll, extrusion, and pelletising) suitable for briquetting organic solid waste.

The **Roll:** Briquetting is mainly for dry granular materials, such as food waste, sludge, and minerals. It uses a screw feeder to direct materials between two opposing rotating presses, which include pockets (Envis, 2006).

Extrusion: Briquetting uses a ram/piston press that move backwards and forwards to push the base materials through a tapered die. The success of extrusion briquetting depends on actual measurements of temperature, and moisture content of 6 to 15%. This ensures the production of quality briquettes (ZEC, 2009).

Pelletizing: This method squeezes solid waste through several holes of a furnace giving high pressure from rollers to the materials. The process produces a pellet with 8-15% moisture content, and energy value of 16.3 - 18.6 MJ/kg (Klass, 1998).

COMPLETE OVERVIEW OF WASTE TREATMENTS

Waste treatment techniques seek to transform the waste into a form that is more manageable, reduce the volume or reduce the toxicity of the waste thus making the waste easier to dispose of. Treatment methods are selected based on the composition, quantity, and form of the waste material. Some waste treatment methods being used today include subjecting the waste to extremely high temperatures, dumping on land or land filling and use of biological processes to treat the waste. It should be noted that treatment and disposal options are chosen as a last resort to the previously mentioned management strategies reducing, reusing and recycling of waste (Michael, 2007).

Fig. 6 portrays the present waste treatment situation. Thin arrows show emerging technologies.

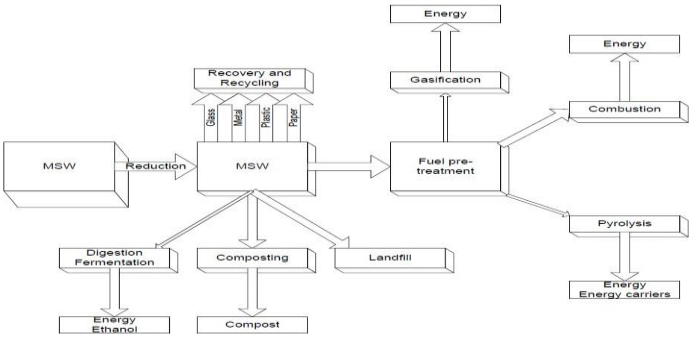


Figure 6: Solid Waste Treatment: A Complete Overview (Klass, 1998).

CONCLUSION

Based on the research carried out on the three methods of Municipal Solid Waste Disposals thus; Biological, Thermal and Physical technologies. However, it was concluded that the most effective way to reduce waste is to prevent it from ever becoming waste in the first place. Waste prevention, is also known as source prevention, is the practice of designing, manufacturing, purchasing, or using materials (such as products and packaging) in ways that reduce the amount of toxicity of trash created. Reusing items is another way to stop waste at the source because it delays or prevents the entry of those items into the waste collection and disposal system. Methods of waste reduction, waste reuse and recycling are the preferred options when managing waste. There are many environmental benefits that can be derived from the use of these methods. They reduce or prevent green house gas emissions, reduce the release of pollutants, conserve resources, save energy and reduce the demand for waste treatment technology and landfill space.

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