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MUNICIPAL SOLID WASTE INCINERATION PLANT FOR ACCRA BREWERY LIMITED (GHANA)

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ABSTRACT

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Waste incineration is a common practice of waste management tool in most developed countries, for the purpose of converting mass and volumes of waste into a very useful energy content.

The aim of this study was to compare the costs benefits of waste incineration for Accra Brewery boiler plant and to investigate also the availability of waste and it´s compositions in Accra, as well as to determine the feasibility of using this waste as a source of fuel to the waste incineration plant.

The analysis was carried out on waste calorific values/content and it was shown that the minimum heat content obtained from waste in Accra was above 7 MJ/kg. Therefore, it makes the waste viable to be incinerated.

The following result has been observed: municipal solid waste incineration plant, the benefit outweighs the cost by one million euro when compared to the existing Accra Brewery boiler plant, indicating the higher profitability of the waste incineration plant.

Regarding the findings made from the study, it sounds logical to conclude that: the result of the cost benefit analysis indicates potentials of economic savings for the use of waste incineration plant; it is therefore worthwhile for the management of Accra Brewery Limited to consider adding waste incineration to their agenda of improving costs savings.

Keywords: Waste incineration, heat composition, calorific values, profitability and boiler plant.

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ABBREVIATIONS

APC	Air Pollution Control
ABL	Accra Brewery Limited
BFB	Bed Fluidized Bed
CM	Carbon Monoxide
CAPEX	Capital Expenditure
CFB	Circulating Fluidized Bed
CR	Chromium
CD	Cadmium
EDTA	Ethylenediamenetetraacetic
HG	Mercury
K	Potassium
MSWI	Municipal Solid Waste Incineration
MSW	Municipal Solid Waste
MJ/KG	Mega Joule/Kilograms
NO_X	Nitrous Dioxide
NH_3	Ammonia
OPEX	Operational Expenditure
LPG	Liquefied Petroleum Gas
PH	Potassium Hydrogen
PB	Lead

RFO	Residual Fuel Oil
SNCR	Selective Non Catalytic Reduction
SO_X	Sulphur Dioxide
S/S	Solidification/Stabilization
TPD	Tons per Day
VOC	Volatile Organic Compound
WTE	Waste-To-Energy

LIST OF APPENDICES

1. INTRODUCTION

Globally, millions of tons of municipal solid waste (MSW) are generated every day. Urban waste management is drawing increasing caution, as it can easily be observed that too much garbage is lying uncontrolled in the streets, causing inconvenience, environmental pollution, and posing a public health risk. Solid waste in recent times has been an issue affecting the citizenry of the greater Accra region.

Accra is the capital city of Ghana, which has a population of about 3.9 million people as estimated by the population census in the year 2014, the amount of waste per/person/day is 0,47kg, which translates into an approximated content of 1833 tonnes of municipal solid waste per day (TPD), of which 45% is collected and transported to the traditional landfill site at Achimota a suburb of Accra central and amongst other areas /1/.

Solid waste which is more easily recognized than defined includes all unwanted or unusable items, byproducts from end users, remains as well as household, residential and industrial garbage.

These wastes contain valuable material that could be used to recovered heat and electricity in various forms, such as heat to energy

Waste incineration is one of the waste disposal methods mostly found in the developed countries, for the purpose it renders by converting volume, masses and chemical reactivity of waste to energy by a process that involves the combustion of organic matter contained in waste materials.

The harmless disposal of MSW is an important issue that draws attention to building a resource-saving and environmental –friendly society, reducing pollution, improving the living environment and the level of ecological civilization. The Ghanaian government is seeking for more effective ways to dispose of MSW compared; with MSW treatment technologies, the waste incineration method will help a lot and is one of the best waste management options. The application of large scale incineration technologies is about to gain grounds to help reduce landfills area in Accra. Thus, the waste-to-energy (WTE) incineration plant will become the best option for Accra Brewery limited, which uses an incinerator to convert MSW to steam.

This incineration of waste materials converts the waste into ash, flue gas and heat. The ash is mostly formed by the inorganic constituents of the waste, and may take the form of solid lumps, whereas the flue gases must be cleaned of gaseous and particulate pollutants before they are dispersed into the atmosphere to avoid negative health impact in the environment. Heat produced by incineration can be used to generate electric power.

Accra Brewery limited (ABL) is a brewery based company in Accra, Ghana and is the second largest brewery company that produced 400,000 bottles of drinks per hour and is listed on the stock index of the Ghana Stock Exchange. It is, one of the oldest non-traditional manufacturing businesses in Ghana. ABL brands include Club Beer, Castle Milk Stout, Stone Lager, Club Cola, Castle Milk Malt, Soda and Quinine Tonic which are produced and marketed worldwide.

Accra Brewery limited uses a lot of steam for brewing the food stuffs for-processing of the drinks as well as washing of bottles and also for preservation purposes and other equipment's and electricity for operation of the plant.

The expenditure for the provision of the needed energy for the operation of the plant is big. Using waste generated from the municipal couple with an incineration plant would help cut down the cost of fuels, such as diesel and residues fuel oil (R.F.O) and to maximize the profit margin of the company.

1.1 Research Question

This thesis aims to answer the following problems:

1. How many tonnes of municipal solid waste would be required to produce the needed energy (steam and electricity) for the plant?
2. What will be the cost benefits of using the waste incineration plant over fuels (diesel and R.F.O) for the production of energy?
3. Why is the municipal waste incineration technology not very much used in Ghanaian industries?

1.2 Research Objectives

This research objective was focused on investigating the quantum of raw material needed to produce 107279 kJ/kg of steam in average and also to ascertain the cost effectiveness/ benefits of using municipal solid waste as a raw material for an incineration plant over the use of fuels, such as (diesel and residual fuel oil) for generation of steam to Accra Brewery limited.

However, the objective still stands to determine how long the plant will be able to pay off its investment cost (break-even point).

1.3 Thesis Structure

The structure of this thesis is focused on a general overview of municipal solid waste generation and management in Accra, Ghana.

Chapter 2 will provide a detailed description of incineration technology based on a thorough review of available secondary information and a review about the existing company technology, incineration types. Chapter 3 will talk about particulate gas and pollution control, combustion process, ash treatment and utilization.

Chapter 4 investigates the availability of solid waste with their heat compositions alongside, reviewing the reasons why waste incineration technology remains unpopular within Ghanaian industries and numerical estimations, cost comparativeness of the technology and also a feasibility analysis of the payback period.

Chapter 5 comprises the conclusions and recommendations.

1.4 Research Methodology

The research is a qualitative method of collecting relevant information in this study. A single phase case study strategy is employed to conduct a review on municipal solid waste generation in the central part of Accra to determine the types of waste and their respective heat values or content and also some findings about Accra Brewery Limited energy/ steam requirements.

2. GENERAL CONCEPT OF MUNICIPAL WASTE INCINERATION PLANT

2.1 Introduction

Municipal solid waste remains the troubling issue in our modern communities, upon the relentless efforts to eliminate, reuse and recover heat. At present times, municipal solid waste incineration in a waste-to-energy recovery plant still remains the best management approach to deal with waste in the developed and other developing countries. The technology for recovering energy from MSW has improved in some decades now with sophisticated air pollution control to ensure that emissions comply with environmental regulation acts. The design of air filter bags, scrubbers, stacks, ash hopper and quencher, all these are an indication of making sure that incineration technology emissions are well controlled and therefore, are acceptable into our societies to assist in reducing the thousands of tons of waste generated.

2.2 Accra Brewery Existing Technology

Accra Brewery is a brewery based company which was established in 1931 and owned by SABMiller which is located at the heart of the Ghanaian capital Accra. This company is multinational which means it has co-existing counterparts across the length and breadth of African continents. The company produces different variety of drinks; alcoholic and non-alcoholic beverages, about 32000 liters are bottled per hour and the company operates 24 hours a day and seven days a week. Accra Brewery is the second largest brewery in Ghana. Its sales volumes of some 400,000 hl represent slightly over a third of the total of Ghanaian market. Per capita consumption of between 5 and 6 liters is low by African standards and suggests a large informal market for homemade liquor. With its rich portfolio of authentic Ghanaian brands, the company is well positioned to capture growth in all beverage categories. Products produced are mentioned and shown on the picture below. These includes Club Gold Export Lager, Club Premium Lager, Castle

Milk Stout, Club Shandy, Stone Strong Lager, Chairman Malt Liquor, Redd's Fruit Fusion, Peroni Nastro Azzurro, Club Ginger Ale, Club Muscatella, Club Orange, Club Soda, Club Quinine Tonic, Club Cola, and Chibuku. Figure1 shows a variety of products produce by ABL.

Figure 1. Products of Accra Brewery

The engineering department is the power house of Accra brewery considering the contribution it put into the production growth of the company. This department is segmented into four phases which are:

- ✓ Co_2 section
- ✓ Water treatment house
- ✓ Refrigeration house
- ✓ Boiler house

The Co_2 section mainly consist of treating and extracting carbon dioxide from the fermentation line going to packaging for filling of the bottles in order to maintained the level of drinks in the bottles. This section works with different kind of technologies, such as foam separated that does the removal of excess foam from the CO_2 gas, there are also pre-chillers and pre-heaters these are all devices that regulate gases temperature to the required mode, CO_2 compressors After the generation of CO_2 it is stored at the balloon and delivered to the packaging department for processes.

The water treatment house is responsible for making sure that the water that comes from the municipality is properly treated and that it does not carry any impurities during and after processes. Chemicals, such as caustic soda and chlorine are added to the water to remove undesirable contaminants from it.

The refrigeration house provides cooling to the equipment, such as the condenser, distributor and compressor

Its ultimate goal is also to provide cooling to the storage vessels/cylinders in order to prevent drinks from getting spoiled.

Accra Brewery is one of brewery companies in Ghana-that still uses old design boilers. The boiler house has four boilers one from John Thompson design that comes from England and three from Cochran design which also come from the United Kingdom the picture below shows the boiler technology this company are using. They are all wet or saturated steam boilers, therefore they cannot generate electricity. These boilers are dual-fuel type, this meaning their fuel intake could be diesel or residual fuel oil. The fuel tanks have a capacity of 4500 liters each and the tanks are kept what is often called the tanks farm. Figure 2 shows the ABL technology (boilers and fuel tanks).

Figure 2. Boilers and fuel tanks

The operation of the boiler, fuel from the tanks comes to the burner through pipelines which are linked together, there are valves and filters within the line that allows for fuel delivery and cleaning before it gets to the boiler. At the burner, there comes a gas electrode from the liquefied petroleum gas (LPG) carries an ignition spark into the burner which has already been prepared the mixture of fuel and air by the primary forced-draught, so a pilot flame occurs and combustion takes place. This time round the LPG delivery stops, as well as the primary air. Secondary air is introduced this time to assist the complete combustion, steam is generated and sent to the various departments for use and steam and the flue gases leave the chamber through the chimney without gas treatment. However, there are series of safety devices found within the boiler, such as, pressure relief valve, safety valve amongst other. These are there to ensure the safety of the equipment as well as the individuals operating it. Components such as economizers feed water tanks and deaerator control the temperature of the water within the boiler preference.

Since the company is running on four boilers two are always on standby whereas one or two run at a time depending on the demand for steam from the departments, this means that the plant operates 24 hours a day and 8760 hours a year. The maintenance phase comes somewhere in September/October since December is the peak production time to the company. To keep the plant in good condition two boilers are shut down for maintenance, which normally lasts for a week or two while the other two, while the other two are put into operation mode after which it goes vice versa.

Boiler dynamics technology consumes about 10500 liters of fuel or even more daily to produce 107279 kJ/kg of steam, this represents an amount of Gh¢ 17850 Ghana cedi, which is equivalent to € 4145.50 euro.

2.3 Waste Incineration Plant Technology

The incineration technology consist of the following key components or parts

- ✓ Waste auto-grid/handle crane
- ✓ Feed hopper
- ✓ Grate
- ✓ Forced-draft fan
- ✓ Tipping hall
- ✓ Furnace
- ✓ Boiler
- ✓ Bottom ash bunker
- ✓ Super heater
- ✓ Economizer
- ✓ Scrubber
- ✓ Fabric filter baghouse
- ✓ Air pollution control residue conveyor
- ✓ Chimney

All components mentioned above make up a complete waste incinerator which performs different roles. For instance, the tipping hall acts as a storage place for waste substance that comes from the communities, the auto grid is a component that is responsible for thorough mixing and feeding of these waste into the combustion system, the feed hopper is just a mere passage for the waste, the grate is capable for hauling waste from the combustion chamber and to give way for complete and effective combustion, the forced-draft fan ensures that enough air is sent into the combustion system allowing for complete combustion.

The furnace is the section of incineration plant where burning takes place, the boiler is a vessel that contains water which is converted into steam by the help of heat exchangers, the bottom ash bunker forms the lowest part of the combustion chamber that act as an ash collector.

The super heater is located within the boiler and converts saturated steam or wet steam into dry steam. The economizer captures the waste heat from the boiler stack gases or flue gases and later transfers it to boiler feed water to assist a quick heat exchange. The scrubber acts as a gas cleaning agent of the waste incinerated; the air pollution control (APC) tries to eliminate or reduce the emission rate of the plant, and finally the chimney is the pass way of the treated exhaust gases from the system to the atmosphere /28/.

2.3.1 Operation of the Technology

Below shows a brief description of municipal solid waste incineration and its principle of operation.

Figure 3. Shows a schematic view of MSW incinerator

Waste is delivered by trucks (1) and discharged into the tipping hall ´´as-received’’ (2), in enough amounts for providing a constant supply of raw material to the plant. Then, waste is randomly picked up through an auto grid (3), and dropped into the feed hopper (4), the waste flows through the feeder (5), into the grate (6), where combustion takes place. The plant is controlled in order to optimize the combustion conditions, to ensure, as much as possible, complete carbon burn-out, and for this the residence time on the grate is usually not more than 60 minutes. The forced-draft fan forces the primary air through an under grate air zone into the furnace in order to supply oxygen to promote oxidation reactions, from point (1). There is a supply of primary air which comes from the tipping hall (2) to lower the air pressure and to eliminate odour from the storage area. Although this is not indicated in the figure above, a secondary air supply is commonly found in the furnace, this guarantees the turbulence of the flue gases (secondary-air) and to ensure complete combustion. The reactions involved in this process are exothermic and release a high amount of energy that is carried over by the flue gases as heat. Energy recovery in the boiler is achieved by a superheater and economizer. The burned-out bottom ashes are normally quenched and transported to a storage bunker and be vitrified and handled as non-hazardous substance. The huge amount of gases produced during the combustion contains air pollutants which are harmful to the environment and it must comply with the stringent regulatory limits. Thus, depending on the desired cleaning degree, different air pollution (APC) systems such as dry/ wet scrubber and fabric air filters are used. The cleaned flue gas is then released via the stack/chimney into atmosphere.

2.3.2 Incineration Furnace Technology

There are three main different types of incineration furnace technologies; these various types operate based on the raw material specifications and the type of combustion system which are categories as mass burning of ´´as received’’ and inhomogeneous waste, and pretreated homogenized waste burning. Mass burning of ´´as received’’ and inhomogeneous waste simply means little or no pretreatment requirement and the other pretreatment is necessary to enable combustion process.

The types of incineration furnaces are fluidized bed, moving grate and rotary kiln

2.3.3 Fluidized bed incineration

The circulating fluidized bed (CFB) and bubbling fluidized bed (BFB) are the major two types of fluidized bed incinerator.

The principle of operation with the circulating fluidized bed varies from the other type, a CFB boiler furnace has an adequate gas velocity to blow the solid particles out of the furnace, and the escaping solids at the furnace are captured and recirculated back to the furnace based on a cyclone/solid gas separator.

Primary air comes into the combustion chamber through the grate. Secondary air is injected through the sides above the furnace floor for complete combustion.

A bubbling fluidized bed incinerator consists of a container vessel made of lined with refractory or heat-absorbing tubes. The vessel contains the bed materials; there is an injection of secondary air into the chamber through the freeboard that is enclosed by heat-absorbing tubes.

This type of a boiler is a sub-section into three different layers: the bed, freeboard and convective section. The increment in velocity forms bubbles which are commonly called the dilute phase. The bed temperature is well maintained below the melting point of the ash.

A fluidized bed is based on a principle where solid waste particle mixed with the fuel are fluidized by air. The scrubber consists of a vertical refractory lined steel vessel containing a bed of granular material, such as silica sand, limestone or ceramic material /33/.

This particular technology has an appealing characteristic in relation to combustion technique: the reduction of hazardous substance in the fluidized bed reactor itself, contained as well as high thermal efficiency, high flexibility regarding multi fuel input and cost. The demanding process of pretreating the waste before it gets fluidized is the key problem with this design.

The operation of fluidized combustion can be obtained in the fluidized bed incinerator by thoroughly mixing fuel and air in a specific proportion; this depends mainly on the size of fuel particles and air density of fuel mixture.

The solid particles which are set into motion by blowing gas steam upwards through the bed at a sufficient velocity to suspend the particles. This bed appears to be like a boiling liquid, so fluidization occurs when the drag force on the particles in the bed due to the upward flowing gases becomes equal to the weight of the bed. Figure 4 below shows a typical circulating fluidized bed furnace combustion system /31/.

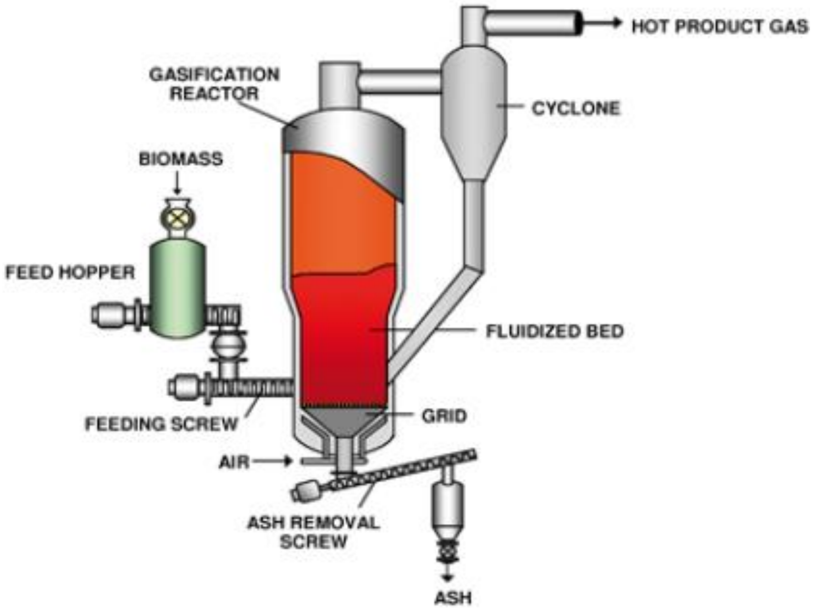

Figure 4 A typical fluidized bed combustion furnaces

Advantages with this technology:

- ✓ installation and maintenance cost is quite better as compare to the other types
- ✓ Easy ash removal system to be transferred for cement processes
- ✓ Overall efficiency of 90 percent
- ✓ Suitable for either solid and liquid waste or separate ways.
- ✓ Highly effective generation of energy due to optimal heat and mass transfer.

2.3.4 Moving Grate Incineration

The conventional mass burn incinerator is based on the moving grate which consists of layers of burning on the grate transporting material through the furnace.

An overhead crane feeds waste into the hopper, where it is transported via the chute to the grate in the furnace. Drying of the waste takes place at the furnace and then burned at high temperature of 850˚C and above with air supply. The non-combustible fractions of waste leave the grate as slag or bottom ash through the ash chute to the base ash collector.

During operation waste is fed into the grate by the help of crane through the opening or throat. From here, the waste has to move towards the ash pit. Waste is further treated and water locks wash out ash from it. Air is then flown through the waste and this blown air works for cooling down the grate or the grate can also be cooled down by water. Secondary air is blown through the boiler to help in complete burning of the gases with the introduction of turmoil leading to better mixing and excess of oxygen.

Figure 5 shows a moving grate furnace of incinerator /29/.

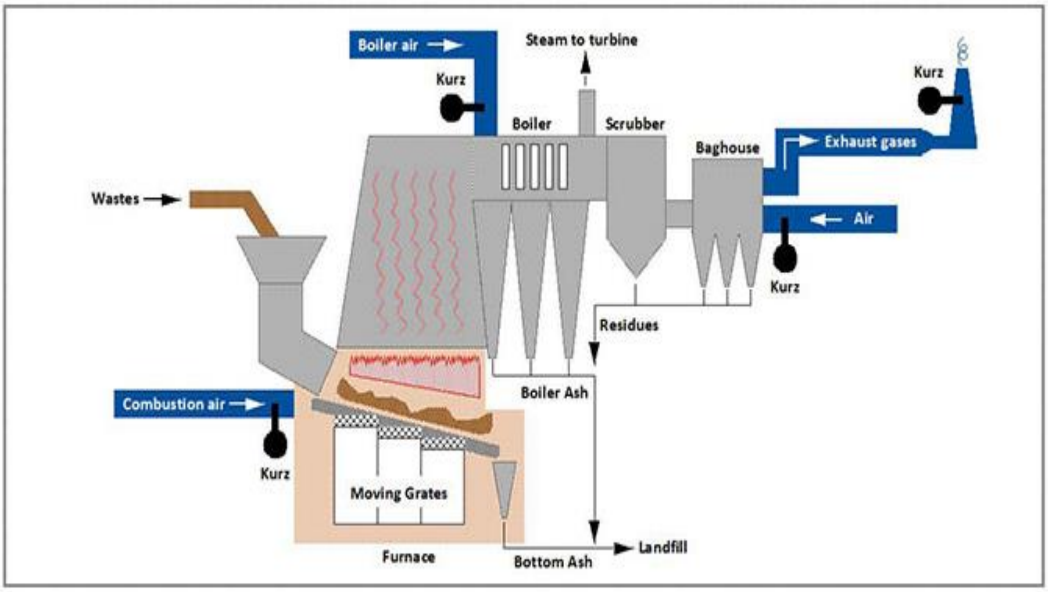

Figure 5 A moving grate incinerator designs

Advantage of this type of technology is.

- ✓ This technology is widely used and thoroughly tested for waste incineration and it has met the technical requirements and demands.
- ✓ Using this technology can achieved an efficiency of 85 percent
- ✓ It has a furnace capacity of 1200 tons per day (50 metric tons/hour)
- ✓ There is no need for prior or shredding

Maintenance and capital cost is relativity expensive for this design.

2.3.5 Rotary Kiln Incineration

The rotary kiln comprise of a layered burning of the waste in a revolving cylinder. These waste substances are transported into the furnace by the rotations of inclined cylinder. The rotary kiln is normally refractory lined but can also be equipped with water walls.

The diameter of rotary kiln is up to 1 to 5 meters and 8 to 20 meters long. The capacity is as low as 2.4 tons per day (0.1 tons/hour) and estimated of 480 t/day. The excess air ratio is well above that of the moving grate incinerator and even the fluidized bed. The retention time of the flue gases is usually too short for complete reaction in the rotary kiln itself, the cylinder is followed by, and connected to, an after-burning chamber which may be incorporated in the first part of the boiler. Rotary kiln could be used in combination with a moveable grate where the grate forms the ignition part and the kiln forms the burning–out section. Thus, this allows for a very low level of unburned material in the slag. Figure 6 below indicates the working principle of rotary kiln incineration combustion process alongside with it waste composition value on table 1. /30/.

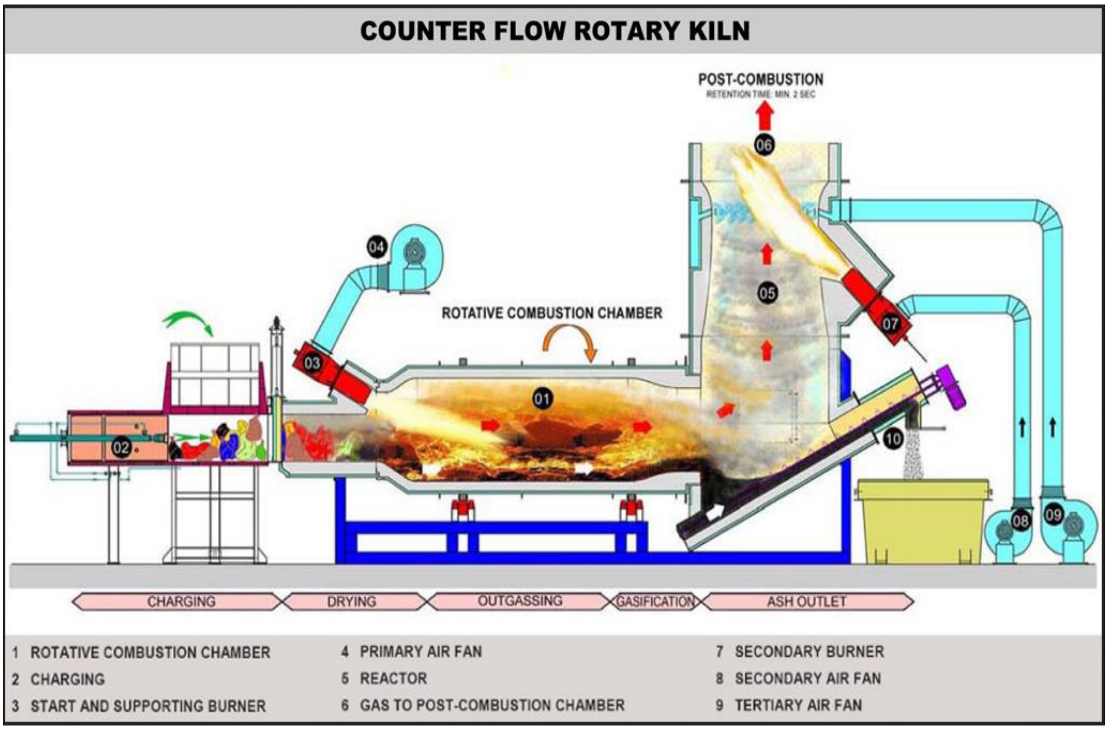

Figure 6. A principle operation of rotary kiln incinerator

Table 1. Below shows a rotary kiln incineration waste properties

Type of waste : Aggregate conditions: solid, sludgy, pasty and liquid	
Heating values:	1 ÷ 45MJ/kg
Moisture:	up to approx.86%
Density:	40 to approx. 1,500kg/m^3
Capacity range: thermal condition:	1.25MW ÷ 8.4 MW
Weight (by H_u of 15MJ/kg);	300 kg/h-1000 kg/h 7.2t/day-24t/day

Advantages of rotary kiln incineration.

- ✓ Ability to burn different variety of waste composition and calorific values
- ✓ It has an overall efficiency of 80 percent
- ✓ No sorting or shredding is needed

The disadvantage of the rotary kiln incineration.

- ✓ High in maintenance and capital cost
- ✓ Limited capacity of waste to be incinerator

3. AIR POLLUTION CONTROL AND ASH TREATMENT PROCESS

This chapter deals with the essential three key elements which have been brought to absolute control with issues regarding air pollution, mainly the disposal of ash and gases which are by-products of the plant. Therefore measures will be implemented to curb these issues since the plant consists of combustion process that emits gases and ash that need to be treated before its final disposal.

3.1 Combustion Process

3.1.1 Waste Storage and Drying Stage

The refuse from the collection point is brought to the plant by tracks of vehicles which are then discharged into a tipping storage hall or pit. Bulky waste, such as furniture is passed through a crusher before the delivery to the storage pit. Overhead grad cranes (auto grid) feed the refuse from the bunker into the incinerator hoppers and subsequently move into the grates, where the refuse is cut into smaller pieces and drying takes place. To achieve drying fuel, radiation, hot waste gases or preheated air to the surface of the refuse. Preheated air is applied drawn in through the underside of the grate surfaces and flows over the fresh refuse to evaporate the moisture.

3.1.2 Combustion in a Furnace

Away from the drying process, combustion takes place at the middle section of the grate. The dried refuse is incinerated and reduced in volume. Since the refuse is heterogeneous in nature, an excess combustion air at 60-100% is supplied to optimize the gas temperature in the range of 850-1200^{0}C. During the process, the air supply must be sufficient to ensure complete combustion of waste and also to prevent the formation of dioxins and carbon monoxide.

3.1.3 Gas Temperature Reduction and Power Generation via Overheated Steam

At this stage, the burnout temperature for incineration should be 850^{0}C with a residence time of more than two seconds. Residual carbon burnout and other burning elements take places. The residue is cooled before discharge at the end of the grate. It is also by requirement that the incineration gas cooling must be carried out before passing it to the gas cleaning system.

The walls of the combustion chamber are welded together with the boiler tubes to allow heat conduction and cooling to take place. The system of exothermic supports the superheating of steam from water and the steam is then use for power generation.

3.2 Municipal Solid Waste Incineration Air Pollution Control

Air pollution from an incineration plant has been a major problem for the past fifteen years because of its gas emissions but thanks to modern advanced technology, a pollution control system has been designed to limit the pollution and to ensure compliance with environmental regulations. This helps to improve and encourage investors and other sensitive agencies to admit this technology since it contributes to waste management globally. A well designed component called scrubber (wet/dry type) use to spray fine atomized slurry or lime powder into the hot exhaust gas in order to neutralize the acidic gases, such as hydrogen chloride and sulfur oxides. An activated carbon column or injected activated carbon spray is used to absorb the heavy metals and organic pollutants, such as volatile organic compound (VOC) and polychlorinated biphenyl (PCB) in the exhaust. A selective non-catalyst reduction (SNCR) system is used to remove nitrogen oxide by adding urea or ammonia. The bags filter systems act and remove the fine particulates and dust particles /3/.

3.2.1 Carbon Monoxide (CO)

Carbon monoxide is always found in flue gas and it represents incomplete combustion of organic compounds that is measured on-line and usually used to check the incineration efficiency.

It is assumed that the presence of CO concentration is always lower in flue-gas than the gas burn out. The CO rises in combustion chambers when there is insufficient oxygen for full oxidation or temperature is not adequate to guarantee full reaction to carbon dioxide. Carbon monoxide oxidation to carbon dioxide occurs after some time its release to the atmosphere /2/.

3.2.2 Nitrous dioxides (NO_x)

Nitrogen oxides are acidic gases and they contribute to global warming. The incineration process has three different mechanisms that can lead to their formation. Indeed, part of the air nitrogen contained in the waste or fuel could oxidize to NO_X. The nitrous oxides produced from air is known as thermal NO_X, and the ones originated from waste as fuel NO_X. The formation of nitrogen oxides through radical reactions with organic compounds is known as prompt NO_X. This has little contribution to a waste-to-energy (WtE) incineration plant.

In order to comply with regulatory limits two strategies are employed; primary and secondary. The main primary techniques involve both air supply and excessive high furnace temperatures. The secondary measures may demand injection of reduction, agents such as ammonia (as 25% aqueous solution) or urea. The 85% reduction of NO_X can be obtained at the temperature of 1000^0C, and thus some ammonia (NH_3) can also be related in the flue-gas /1/. When urea is used as a reducing agent in selective non-catalyst reduction, a little N_2O may arise /2/.

3.2.3 Acid Chloride and Fluoride

The presence of chloride and fluoride in municipal solid waste incineration comes as a result of burned plastics, such as polyvinyl chloride (PVC), salty food waste and other inorganic chlorides. The character of fluoride gases may turn into polytetrafluorethylene (PTFE), fluorinated textiles and other inorganic fluorides. The condition of the furnace converts fluoride and chloride into acid hydrogen halides, hydrogen chloride (HCl) and hafnium (HF) and part of these may react to form metal chlorides. By neutralization process HF and CHl can be removed in support of lime, sodium hydroxide or calcium carbonate. The reaction formulas below indicate the removal of acid pollutants with calcium hydroxide ($Ca(OH)_2$)

$$2CHI + Ca\,(OH)_2 \rightarrow CaCl_2 + 2H_2O \quad (1)$$

$$2HF + Ca\,(OH)_2 \rightarrow CaF_2 + 2H2O \quad (2)$$

Above reactions entail complex mechanisms due to various gas/solid phases involved, and some studies refer that instead of calcium chloride ($CaCl_2$) the main phase formed is CaOH. Concentration of gaseous emissions in general ranges from 0.1-6mg/Nm^3 for HCI and 0.01-0.1mg/Nm^3 for HF, and thus falls below the regulatory limits /2/.

3.2.4 Sulphur Dioxide (SO_x)

Sulphur dioxide is a reaction product of S-compounds contained in the waste with oxygen, and its concentration in the flue-gas is proportional to the amount present in the waste:

$$C_xH_y\,S + wO_2 \rightarrow CO_2 + HO_2 + SO_2 \quad (3)$$

Nevertheless, whether in inorganic or organic form, some of the sulphur oxides end up in stack gases as SO_2. According to BREF (2006), regardless of the regulatory threshold of 50mg/Nm^3, most of the installations reveal emissions lower than 20mg/Nm^3. The removal takes place utilizing the following reaction;

$$SO_2 + Ca\,(OH)_2 \rightarrow CaSO_3 + 1/2\ H_2O \quad (4)$$

It is important to observe that SO_2 is a highly reactive gas with short half-life indoors. Although it is known to be a respiratory irritant and bronchoconstrictor, the effect of these gases is limited to asthma patients but, injections of ammonia or slurry by the scrubber into this content neutralizes the harmful reaction nature therefore making it as carbon free gas /2/.

3.2.5 Other Heavy Metals

At the stage of the incineration, combustion temperatures attained in the furnace determine the evaporation degree of heavy metals and most of inorganic salts. Mercury (Hg) and copper (Co) also lead (Pb) and manganese (Mn) all must be under control in stack emissions. Since all these gases are carcinogenic that provokes respiratory system of living organisms. Most of these metals are in flue-gas as oxides or chlorides, which condense onto dust particles as the gases cooled down to the downstream of the boiler. Therefore, it is expected that the part of these metals that evaporate in furnace, will definitely ends as condensed phases in air pollution control residues, therefore reducing these metals reactions to considerably limits. Activation of carbon takes away the all the stubborn gases /2/.

3.3 Process Ash Treatment Methods

The act of proper utilization of waste and the consequences of its impact on the environment draws a wider public interest as how to find measures/solution to these problems in order to maintain quality environment and lives as a whole. The ash treatment process is carried out in different ways and methods depending on the nature of the ash. The separation process starts first followed by thermal treatments and the last is the solidification/stabilization process. All these techniques will help to manage the ashes. Therefore to receive good results, three most well organized strategies were deployed. They are: /27/

- ✓ Separation processes
- ✓ Solidification
- ✓ Thermal methods

3.3.1 Separation Process

The aim of separation methods is to improve the quality waste ashes and to enhance their utilization. The techniques include washing, leaching, electrochemical process and thermal treatment.

3.3.2 Washing process

The objective of this process concentrates much on reducing the chloride, salt, alkali and heavy metal substances by using an application known as leachant (liquid solution) such as ordinary water and acid. These contaminants could be found on both bottom and fly ash based on what process is used, but most often the temperature is considered also, heavy metals and alkali predominantly remain in the bottom ash, chloride and salt.

One major reason behind the removal of chloride is the fact that it enhances the quality utilization of depending on the temperature, particle size abs liquid to solid ratio, so it is assumed that this process required calcium (Ca), sodium (Na), potassium (K) and chlorine (Cl) removal with a percentage 72.8% at 10:1 liquid/solid ratio and about 12.3 % removal of Cr is achieved /26/. The required procedures for chloride removal are breakdown into the following mechanisms: physic-chemical dissolution of chloride crystal; internal diffusion of ions out of the solid matrix; external diffusion of the ions in the surrounding stationary liquid-film around the ash particle. During the heavy metals recovery process the most factors to consider is the pH control and the liquid-to-solid ratio.

Comparing CO_2 to acid washing it is suggested that to achieve higher efficiency it is recommended to use acid washing whereas CO_2 bubbling enhances the removal of insoluble chloride in fly ash. Another alternative is water washing but the issue with this process is that large amount of heavy metal will react against the soluble salts, however with a repulsive application of controlled pH content could subdue the whole problem.

3.3.3 Leaching Process

The leaching process is employed to ensure that heavy and other solid metals are drawn out of the ashes and to further recover these materials from a severe leachant solution. In order to be able to recover heavy metals it is considered to be at its maximum concentration to allow easy recovery process. The cause of heavy metal leachate largely reflects on the type of extraction solvent, that is to say that the pH, as well as the liquid- to-solid ratio.

According to Youcai, an increase in pH in the leaching solution will lower the leachability of heavy metals as insoluble hydroxides will form at higher pH, it further suggest that by using ethylenediamenetetraacetic acid (EDTA) might be a better option for extraction of the heavy metals. Hydrogen chloride (HCl) is another alternative of extracting metals in MSW fly ash, which is dependent on the pH content while chelating agents are independent of the ph. The maximum extraction of chromium (Cr), Cu amongst others in fly ash obtains 0.3-1 concentration of chelating agents./5/. Considering the recovery process between lead and zinc from the fly ash; the content is acceptable, but the cost performance is less effective./4/.

Newly, pre-treatment bioleaching technology for extraction of heavy metal was carried out by Wang. This was also considered to be a relevant substitute technology to the conventional methods of heavy metals removal in fly ash/7/.

In another study leaching agents were assess for MSW fly ash where it was concluded that using strong mineral acid gives in high leaching of many elements; organic acids were less effective as leaching agents for metals; EDTA demonstrate a quality way of taking off some metals such as Cu and Pb; NH_4NO_3 was a strong removal by Cu. Leaching is one of the most important practice of promoting MSW fly ash alongside in a recovery of some metals for re-use/8/.

A series of investigation about hydrothermal process was carried out in determine the effect of temperature during metal extraction. The MSW ash has to be pretreated by water washing and this process helped achieved about 67% of Na, 76% of K and 48% of Ca.

The use of hydrothermal treatment process speeded the dissolution of the ash and promoted the reaction of acid with toxic metals like Cr, Cd and Pb. The metal reactions during the hydrothermal precipitation and hydrothermal leaching under hydrothermal conditions, the optimum condition presented that hydrochloric acid carries a reaction with 10:1 liquid/solid ratio under 150^0C for five to six hours. Under hydrothermal conditions, the solid reacted with all metals in the ash while the calcium reacts at ambient conditions /9/.

3.3.4 Electrochemical Process

The reason behind this process is to assist in heavy metals removal and again to help to further recover these metals. With this process an application of electric potential forces the reduction or oxidation reactions on the surface of the cathode and anode. During this reaction stage, metals are deposited on the surface of cathode, but the processes do not include chemical and addition. A combined treatment (washing + electrochemical process) was proposed by Ferreira and the results show that a greater reduction of heavy metals in fly ash was achieved /10/.

Figure 7 below indicates a working principle of electro dialytic remediation/15/.

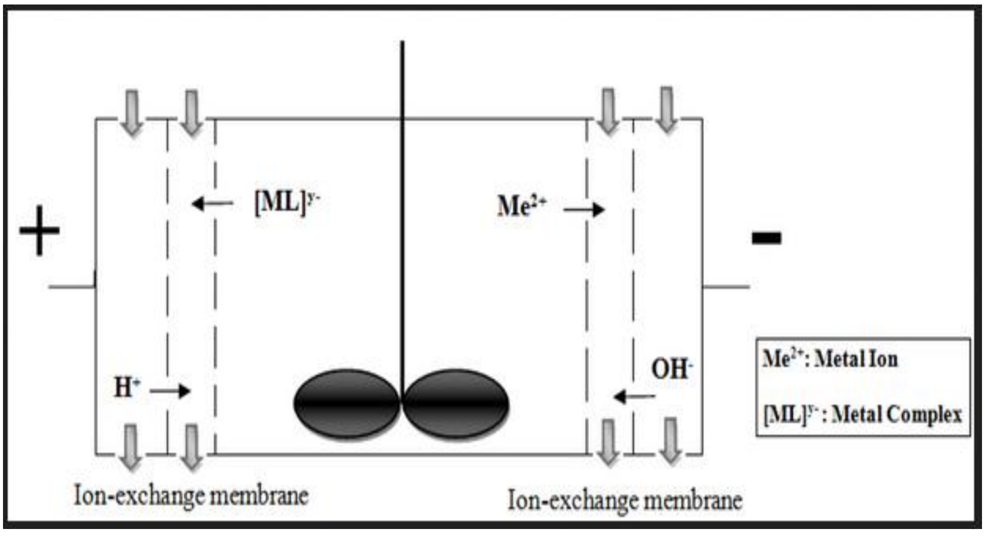

Figure 7. A working principle of electro dialytic remediation

3.3.5 Solidification Methods

This solidification/stabilization (S/S) process seeks to combine additives in a form of physical or chemical stage to fight the hazardous substances present in waste. The main function of stabilization in the ash treatment process is to reduce the solubility and toxicity to certain contaminants that pose a severe threat to the soil. For solidification, normally binders such as cement are used to enfold/enclose the waste material in order to prevent contaminants and reduce leachability.

The addition of Portland cement for s/s is widely used in some part of the world. However, the drawback of this process is that it’s unable to treat soluble salts and long-term leaching will be an alarm environmental issue and also the volume of waste is going to increase in quantity this method is used. However it is the most appropriate design for toxic waste material treatment. Integration of new stabilization technique can be implemented in four different ways: elimination of alkali chlorides by dissolution; addition of phosphoric acid; calcination and solidification with cement. This process can reduce toxic organic, reduce heavy metal reactivity and solidify hazardous waste without exceeding limit.

A combined washing-immobilization process for fly ash treatment has the capacity of utilizing water washing to eradicate significant amount of chloride and sulfate from the ash and to promote the formation of hydrate phase, by converting the heavy metal into less effective conditions. Then the wastewater can be treated by reducing pH to 6.5-7.5; precipitation of aluminum hydroxide occurs, then absorption of cadmium, lead and zinc ions onto the floc particle of aluminum hydroxide. When it comes to s/s treatment methods it is cost economical and viable process of obtaining quality and better results in turns of ash treatment and utilizations./32/

3.3.6 Thermal Methods

The thermal process has the widest capacity of reducing volume of waste by 60% or even more; this method is a highly resistant to leaching and therefore accepted to be more environmental friendly, its secondary raw material are considered to be the easier ones. The equipment operates under a temperature ranges between 1200-1400^{0}C that is used to effectively destroy dioxins furans and other organic compounds /11/. At this treatment process there is a second phase for reuse of the melted slag as a resource. The cost of this technology is usually high and the release of contaminants during the melting is also possible, therefore causing air pollution that needs to be address /12/.

In Japan, vitrification and fusion of bottom ash is put into used at some facilities and the reuse of treated ash was as a secondary raw material has been showed. The issue of heavy metals recovery from fly ash for recycling to smelters is being developed and test has been run successfully and it is economically acceptable. Vitrified bottom ash has a lower standing leaching value than original bottom ash. The process is energy intensive; however, if environmental regulations will be highly restricted in the nearby future and metal slag produced is market valuable, then one will conclude that vitrification would have grounds to hold bottom ash treatment/13/,14/.

The figure below shows a thermal ash melting furnace technology which operates at a temperature of approximately 1,350^{0}C, by the help of flame from the burner and heat radiation from the furnace walls. The nature of this design makes it less fuel consumption. Figure 8 shows a diagram of a typical fuel type surface melting furnace /33/

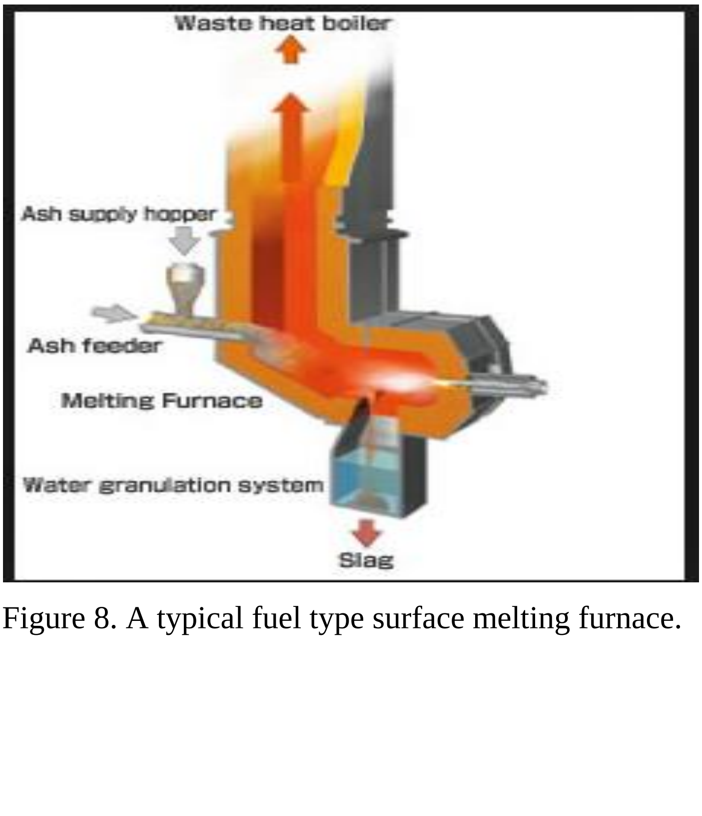

Figure 8. A typical fuel type surface melting furnace.

3.4 Municipal Solid Waste Ashes Application

Below are six different ways in which MSWI can be utilized ranging from; road pavement, agriculture, cement and concrete production, glasses and ceramics, adsorbents and stabilizing agent.

3.4.1 Road Pavement

Every normal road pavement contains different kinds of layers, which comes with different material selection. It is well demonstrated on the figure below in every construction phase. The topmost part of the layer of a sealed pavement is wearing course. This should be even, durable and highly skid resistant.

The most common materials considered for wearing courses are the bituminous surface dressing and asphalt concrete. The layer before the wearing course is the base course, indicating the main load-spreading layer. The base may consist of premixed asphalt, cement concrete, graded granular gravel, crushed rock, or materials stabilized with lime or cement. The sub-base follows rightly before the course base layer that is normally constructed from natural gravel or from materials stabilized with cement or lime. The subgrade is the lowest layer within the pavement, which acts as soil foundation/15/. Figure 9 shows a practical view of a road pavement construction/34/.

Figure 9. A practical view of a road pavement construction.

In order to maintain reuse of MSWI bottom ash it is required to substitute the materials in the base course and sub-base. In regard to road pavement on bottom ash, this provides a simple and direct method for reuse of the incineration ash /16/.

The volume of roads has come to make good use of MSWI bottom ash in construction. A test road was built in Sweden and the bottom ash was used as a sub-base material. It was found that substituting gravel in the road base with the bottom ash does not affect the release of Ca, Co, iron (Fe) and etc. (nitrate-nitrogen) and Pb to the environment. Another three-year study on the utilization of MSWI bottom ash in road pavement in France, showed the concentrations of heavy metal, fluorides and pH values in the leachate were below the limits authorized for potable water. It was then commended to be usable since it does not have any safety threat on waters bodies. Similarly, a survey was conducted in Japan about melting and stone production where a plant was built to utilize MSWI fly ash for stone production. The application of stone production is for permeable-pavement, with 85 wt% of the grounded stone.

The issues with these technologies has to do with leaching of contaminants into soil and groundwater causing several pollutions so it is commendable to propose pre-treatment, such as water washing to reduce the concentration level. Washed stabilized bottom or fly ash is the right alternative to curbing any problem for road pavements construction.

3.4.2 Agriculture

Potassium, nitrogen and phosphorous are the basic nutrients required by plants for their essential growth, and both ash from bottom and municipal solid waste incineration have been found to contain quiet a substantial amount of K and phosphorous (P), which can be used to augment commercial fertilizers used for growing crops. Lime obtained from fly ash can also be used as a liming agent to reduce acidity in soil, which is good for the environment, but applications must be restricted.

This is because bottom ash contains heavy metals and the toxins will affect animals and plants alike, Salt stress is found in plants which will affect the PH value in the soil that would definitely hinder the movements of the elements, Another environmental concern has to do with the leaching of heavy metals into the ground water supply which is an environmental concern or major worry. As a result of these environmental concerns, more research has been carried out in this field /17/.

Bottom and municipal solid waste incineration fly ash can influence the growth of plant in a positive way. This is because crops grown from potassium and phosphorous fertilizer was similar in nature to Swiss chard and alfalfa grown in soil amended with ash after tests were carried out, stressing on the point that ash from municipal solid waste supplies enough nutrients for the growth of plants. Since there is an uptake of cadmium (Cd) and high levels of molybdenum (Mo) in the plant tissue, there were enough reasons to raise concern if the plants are to be ingested by livestock, such as goats, swine and cattle. Problems are caused when high amounts of soluble salt are applied to plants which are sensitive when the amount of ash for amendment is high /18/.

3.4.3 Cement and Concrete Production

Municipal solid waste incineration ash contains the following gases calcium oxide, silicon dioxide, iron (iii) oxide and aluminum oxide, and this is considered be the largest raw material in mortar and concrete production. The composition of fly and bottom ash is quite close to that of raw material for cement production. This could be a potential replacement of raw material in Portland cement production/19/. R. Kikuchi has shown that an additional amount of MSWI ash for clinker production will decrease the time frame and workability; he further suggested that a delay in agent such as gypsum must be included.

The figure below shows a schematic diagram of the cement production process; this process indicates the amount of energy consumption and emission of carbon dioxide during the production phase, which causes a lot of global warming industry day-to-day activities. Carbon dioxide emissions and global warming effect reduction is the seeming advantage of using MSWI ash as a raw material for cement production.

As a huge amount of energy is required to decompose the calcium carbonate ($CaCO_3$) to lime (CaO), a large quantity of carbon dioxide is dispelled during the act of production. As a result of MSWI of bottom and fly ash with its containment of lime instead calcium carbonate, this can reduce emission of carbon dioxide. Several technical issues discourages this application; the high chloride content will affect the product quality, and the cycling effect in the cement kilns causing constant clogging and corrosion inside the heat exchangers. High concentration of heavy metals calls for a solution to environmental problems.

Therefore, there is a need to pre-treat these ashes to further remove chloride and heavy metals content. A caution ought to be taken as in measureable quantity of these MSWI to ensure safe working environment as well as the equipment life guard. Figure 10 shows a practical working design of a cement production /35/.

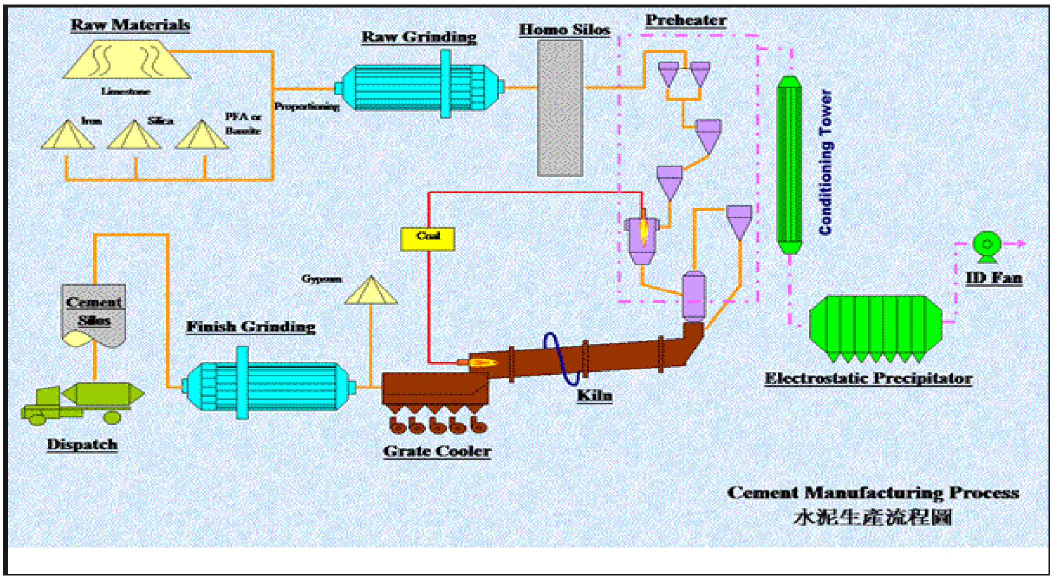

Figure 10. A practical working design of a cement production

Hydration behavior of cement clinker, alkali metal content enhances hydration and contents of zinc (Zn), Pb and cadmium (Cd) slows the rate of hydration of cement. After pre-treatment of the ashes, alkali metal content is reduced and the hydration rate of washed MSW ash containing clinkers is lower than the raw MSWI ash containing /20/. Fly ash contains high chloride and sulfate content, which reveals the formation of ettringnite phase in the hydration period, thus reaction slows down the increasing fly ash content.

Stabilization technology about MSWI ash has the possibility of replacing cement or as an aggregate. It is suggested that 50% of the treated ash will not necessarily affect the strength and the hardness, whereas the leaching property is acceptable for application in road construction.

However, the determination of it lasting period has not been evaluated. It is feasible to use MSWI ash as concrete aggregate. The results show that treated (immersion in sodium hydroxide for 15days) bottom ash can replace up to 50% of gravel in concrete without affecting the durability.

The ash needs to be treated before its application to prevent cracking and swelling. This happens when the reaction between metallic aluminum and cement is not met properly. One application of this ash is for lightweight concrete aggregate by processing into pellets. Since this maybe suitable for non-structural applications, such as interior walls for insulating purposes, Portland cement mortar reuses solidified –cement as an artificial aggregate.

Leaching remains the environmental threatening issue of this application. Although many results indicate that heavy metal leaching is irrelevant, unexpected heavy metal leaching may occur when the structure is pulled down or comes in contact with rain. Countries like Poland and Japan shares the greatest portion of using this clinker cement from ash which is popularly known as enouncement.

3.4.4 Stabilizing Agent

The application of MSWI ash keeps expanding as authorities examined its usefulness within communities this substance is again used in landfill interim cover. The co-digestion of MSW with a proper amount of ash could facilitate bacterial activity, digestion efficiency as well as methane gas production rate. Studies have shown that harmful heavy metals releases ion-like chloride which does not contain significant impact on anaerobic digestion.

Furthermore, the possibility of using MSWI fly ash as s/s binder to treat heavy metal-bearing sludge has been examined. In order to achieved a stabilization and solidification disposal there ought to be optimization process where 45% of fly ash, 50% of sludge and 5% of cement to give a complete outcome. This co-disposal approach can reduce the enlargement of landfill volume and effectively stabilize heavy metals/21/

3.4.5 Adsorbents

The adsorbent approach is one of the methods used to activate carbon and remove pollutants from water bodies. The major concerns for using incineration ash for wastewater treatment is leachability of heavy metals which appears to be everywhere within the context of ash treatment and utilization due to it toxicity nature on our waters. The bottom ash appears to more dominant than fly ash in adsorbent. The leachate of heavy metals in fly ash reduces the potentiality to use it as adsorbents.

In contrast, the bottom ash rarely releases hazardous heavy metal in the leachate. The cation exchange capacity of MSWI bottom ash is the total amount of exchangeable capacity (milliequivalents per 100 grams of adsorbing materials). It is important to compare adsorption capacities for different materials. It has also been shown that the cation exchange capacity (CEC) greatly depends on the particle size of the bottom ash. It has also come to noticed that the smaller the particle size, the higher the CEC value and surface area. The rate of increase in heavy metals adsorption correspond to a decrease in bottom ash particle size, which then means that the adsorption rate is proportional to the particle size and specific surface area. The cation exchange capacity is used to remove nickel (Ni) and Cu from plating rinse water with pH of 3.8 /22/.

Bottom ash is used as an adsorbent for removal of dyes from wastewater. Gupta et al. /23/, studied the removal of dyes from wastewater using bottom ash from MSWI from Belgium, the results showed that the removal of dyes are up to 98% by the batch method and the adsorption capacity is comparable to other available adsorbents.

The pH optimization for dye adsorption ranged from 5 to 8 which solely depend on the chemical structure of the dye molecules. Low-cost bottom ash assists in quicker removal of dye from wastewater. Moreover, bottom ash is also considered as a gas purification agent and it once again helps to remove sulphur compounds, hydrogen sulfide and, methyl mercaptan since this does not affect the energetic content of the landfill gas as methane gas is not retained in bottom ash.

A research has shown that one kilogram of bottom ash is able to sequestrate more than 0.3 g of hydrogen sulfide, 44 mg of methyl mercaptan, and 86 mg of dimethyl sulfide. One key advantage of using fly ash is that it has neutralizing ability therefore can be used for treating acidic industrial wastewater because it contain excess of lime. HCl and SO_2 in the flue gas in MSW incinerators can easily be removed by this process as well.

3.4.6 Glasses, Glass-Ceramics and Ceramic

Bottom and fly ash from municipal solid waste incineration are raw materials that can be used to produce ceramics, glass ceramics and glass at high temperatures that exceed 1000 °C and above.

Municipal solid waste incineration ash mostly contain silicon dioxide (SiO2), calcium oxide CaO and aluminium oxide (Al2O3) which are the basic materials derived after the burning has taken place. Fly and bottom ash from municipal solid waste incineration can either be used to augment or replace clay which is used in the production of ceramic tiles without having to do with pre-treatments /24/. Due to high organic and chloride contents in the fly ash it was realized that it brought about some major changes in the structure of the ceramic tiles, but when 20 wt % of bottom ash was introduced into the ceramic tile either the thermal or mineralogical behaviors did not change the structure that much.

A research has shown that 20 % of fly ash added to the ceramic tile, showed a high compressive strength and a low water absorption rate after 960 °C sintering. Heavy toxic metal leaching in the fly ash was reduced to about one-tenth, in the acceptable durability test it was obtained that 50% of municipal solid waste incineration ash can be added to the production of ceramic tiles without any problem. Efficient techniques, such as the vitrification process is a good way of treating hazardous waste to convert toxic and heavy metal substances into amorphous structure of glass without much problem.

Dioxins are toxic substances that also decompose when the temperature is over 1300 °C, and products like blasting grit, some road based materials, embankments from vitrified ash are all good materials used in the decorative and production industry to produce good pavement bricks, water permeable blocks and ceramic tiles. It has been observed that fly ash from a domestic waste incinerator after it has been heated to about 950 °C within two hours and over has high potentials to be molded or manufactured into good light weight bricks used in engineering applications.

Fine grain polycrystalline obtained from glass-ceramics are composed when suitable glass materials are formed when they are treated with heat and undergo a controlled crystallization to a lower energy of crystalline state. Both thermal and glass ceramics enjoy levels which are far superior to those of their parent glass as a result of the distinct properties it enjoys, meanwhile glass-ceramics have a wide range of applications. Various silicate based waste would be used in the production of glass-ceramic. Glass produced by the vitrification of incineration ash has been found to possess a more ideal quality for the production of glass-ceramic as a result of its thermal and mechanical properties. Successfully ash from the vitrification process has been used as a raw material to produce glass-ceramics and its properties changed tremendously due to the temperature changes and heat treatment.

It has been proven that ash from a municipal solid waste incineration has a low melting point or temperature when there are additives. A research has shown that about 1200 °C is needed for the process instead of the standard 1500 °C, which makes the entire process less energy intensive and friendly to the environment because it requires less energy for production /25/.

The low percentages of ion and metals are released from the nitrifications process used in producing glass as compared to ash from the incinerator. Glass and glass-ceramic from the municipal solid waste incineration fly ash may leach toxic substances from the glass matrix but investigations have shown that the leaching of heavy metal ions are well below environmental regulations from the glass-ceramic and glass.

4. WASTE CHARACTERIZATIONS AND COMPOSITION IN ACCRA (Ghana)

4.1 Introduction

Solid waste management in presence times has become a major challenged in the capital city of Ghana, Accra, primarily among residents living within high-density, medium class income and low-income communities. Mismanagement of solid waste has resulted in a large quantity of the domestic refuse being dumped into open areas and storms drains. The clogging of storm drains has worsened the sewage and sanitation issues, causing subsequent flooding and pollution.

Among the waste generated are organic and inorganic waste materials. Organic matters includes food wastes, plastics, paper, textiles and yard wastes whereas in-organic matter is dust, glass, metals and other miscellaneous components. The composition and quantities of MSW usual takes a different form within a particular community or locations depending on many factors for example, the area, population size, seasonal changes, public awareness of waste sorting, regional and local economic differences, social structural, collection methods, etc. Land disposal of municipal solid waste in landfills has incrementally become dominant due to the increasing amount of MSW generated as a result of rural-urban settlement.

However, landfilling of municipal solid waste has become a less attractive management choice due to limited availability of landfill capacity. In addition to this, the issue with land leachate generation caused by the exin-filtration of rainwater as well as other heavy gases like methane, sulphur and argon gas production led to decomposition of organic wastes.

Incineration is becoming the world’s greatest alternative technology for municipal solid waste treatment with a lot of unlimited advantages of achieving up to about 85 to 90 percent reduction of the masses and volumes of solid waste, making a reasonable reduction of its chemical reactivity by destruction of the organic compounds, for provision of steam generation or heat for electricity.

4.1.1 Study Area

As mentioned earlier in Chapter 1, Accra has a human population of about 3.9 million. The capital town of Ghana is called Accra which covers a total geographical land size of 173 km^2 (67 square meters) for the city and 894 km^2 (345.18 sq. mi), and is the anchor city of the Greater Accra Metropolitan Area (GAMA), which is made up of the Accra Metropolitan Districts. The map below indicates the study area where the waste-to-energy incineration is going to be built and to help identity the characterization of the waste composition generated by its inhabitants. A study by Bernard Fei-Baffoe shows that an approximated content of 1833 tonnes of waste is generated per day /1/. Figure 11 shows a map of the study area in Ghana highlighted in red (Accra)

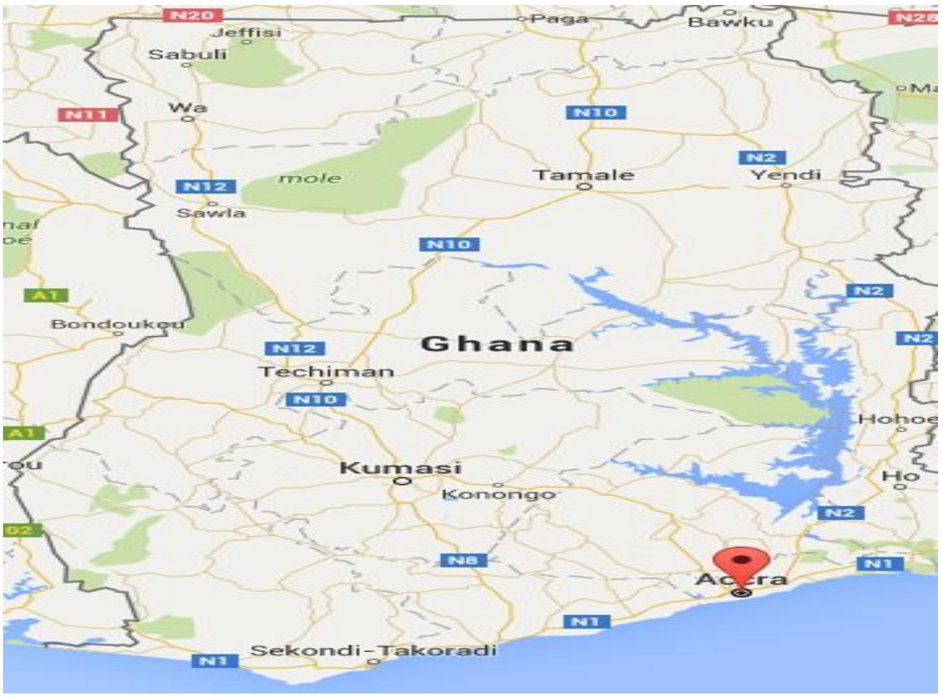

Figure 11. A map of study location in Ghana

4.1.2 Assessment of Calorific/Heat Values of Waste in Accra-Ghana

The calorific value or energy density of municipal solid waste is largely dependent on the moisture content of the waste. It is undisputable that the heating value of any waste depends on it moisture content, i.e. to say the higher the moisture content, the lower it heating value. There is a need to read between two lines about the minimum heating value of MSW, which contains water and the maximum heating value of MSW which is in the absence of water.

A survey has been conducted in Accra to determine the mean values energy densities of MSW components from urban waste zone in Accra, Ghana. The moisture content of MSW was found to be about 50 % that contains moisture in any quantity of waste. However, municipal solid waste in Accra is estimated to be about 17 MJ/kg and this has been widely produced by organic waste, contributing to 60% of the overall average waste stream /1/.

The table below shows the heat values of different waste fractions, for some reasons the heat values differ significantly. So in every material recovery process, hard plastics, glass, paper and cardboard and metals are assumed to be materials recovered and biodegradable (organic/putrescible) waste is assumed to be digested. Composting in this particular case was left behind because from an energy point of view, digestion is the most biological treatment method followed by soft plastics, textile, leather, rubber and other combustibles are assumed to be incinerated and non-combustibles materials are sent for landfills. But in energy recovery scenarios, all waste is assumed to be incinerated.

Table 2. Waste components with calorific values

Components	Energy Content (MJ/dry.kg)
Plastics	30
Paper and Cardboard	16
Textile, rubber & leather	17
Glass & Metals	0
Biodegradable (organic/putrescible)	9
Other, Combustible	16
Other, non-combustable	0
Moisture content	50.0%

4.1.3 Generation and Composition of Sub-Fractions of Household Wastes from Accra.

The sub-fractions waste analyzed are shown in Appendix 1. Food waste recorded bulk of organic waste, averaging 47% of the entire solid waste analyzed and 78% of the organic fraction. The large fraction of the food waste generated 0.47kg/person/day gave chance to divert these quantity of waste into anaerobic digestion prescribed as the best means of handling this type of waste. Yard waste was the next higher fraction of organic waste with 11% of the MSW stream.

Since organic waste is commonly used in Ghana for composting and landfill and it is practiced by few individuals, however, according to Bensah et al. Cardboards formed the highest fraction, 60% of papers wastes and 3% of the entire waste stream. Paper recycling has not been widely utilized by industries.

Plastics waste which consist of low-density polyethylene (LDPE), high-density polyethylene (HDPE), polyethylene terephthalate (PET) and polypropylene (PP) with percentages of 4, 3, 3 and 1.4 respectively in the MSW. LDPE are often used for food packaging.

The data gave foreknowledge to the percentage of waste generation in Accra and methods of treatment to these substances.

4.1.4 Composition of waste in Accra, Ghana

The figure below is a pie chart that indicates solid waste composition in Accra. The largest portion of the pie chart 46.6% represent organic waste, followed by Others which had 29% of the overall waste collected, paper and cardboard recorded 13 % and the remaining ones occupied about 11.4%. Therefore, this has given a foreknowledge of the type of waste and energy that can be obtained from these waste substances.

Studies have shown that waste with calorific value of 7 MJ/kg and above can be incinerated /1/.

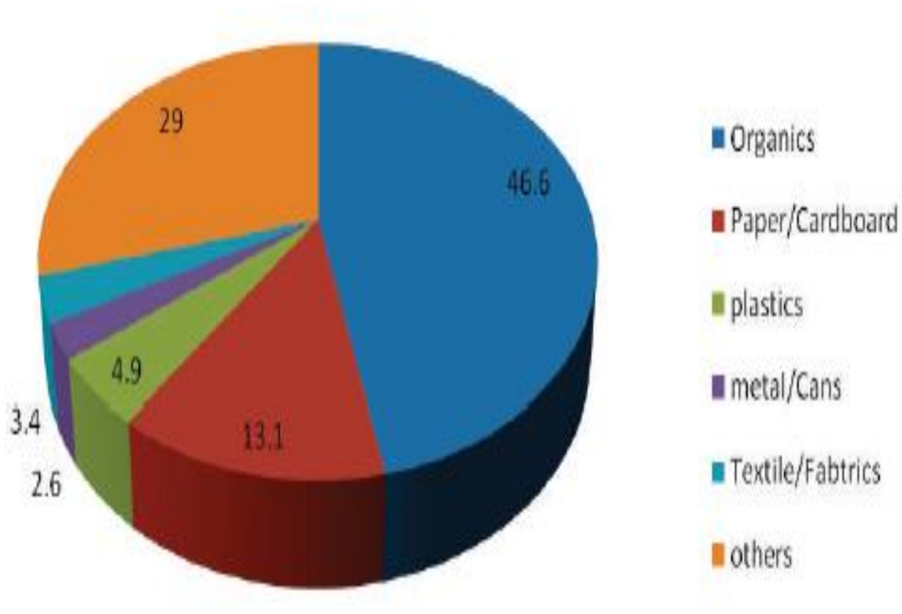

Figure 12. Waste composition in Accra

The composition of waste and the calorific values:

- 46.6% Organic material @ 9 MJ/kg
- 13.1% Paper @ 16 MJ/kg
- 4.9% Plastic @ 30 MJ/kg
- 23.4% Textiles @ 17 MJ/kg
- 2.6% Metal/cans @ 0 MJ/kg
- 29% Others @ 0 MJ/kg

To find out how many MJ/tonnes can be obtained out of the waste, first the calorific value is multiplied by 1000 to get the number in tonnes, and then divide it by 3600 to get the MJ into MW.

- Organic material: $\frac{9\frac{MJ}{kg}}{3600} * 1000 = 2{,}5\ MW/t$
- Paper: $\frac{16\frac{MJ}{kg}}{3600} * 1000 = 4{,}4\ MW/t$
- Plastic: $\frac{30\frac{MJ}{kg}}{3600} * 1000 = 8{,}3\ MW/t$
- Textiles: $\frac{17\frac{MJ}{kg}}{3600} * 1000 = 4{,}7\ MW/t$

Taking into account the composition, the total MW/t and MJ/kg is received from the following calculation:

MW/t

$$\left(2{,}5\frac{MW}{t} * 0{,}5\right) + \left(4{,}4\frac{MW}{t} * 0{,}13\right) + \left(8{,}3\frac{MW}{t} * 0{,}049\right) + \left(4{,}7\frac{MW}{t} * 0{,}23\right) = 3{,}329\frac{MW}{t}$$

MJ/kg:

$$\left(9\frac{MJ}{kg} * 0{,}5\right) + \left(16\frac{MJ}{kg} * 0{,}13\right) + \left(30\frac{MJ}{kg} * 0{,}049\right) + \left(17\frac{MJ}{kg} * 0{,}23\right) = 11{,}98\frac{\mathrm{MJ}}{\mathrm{kg}}$$

Per calculation it can be seen that the calorific value is above the lower limit at 7 MJ/kg, making it feasible.

The total amount of nominal power in the waste:

0, 47 kg/person/day * 3.9 million people = 1,833 tons

1,833 tonnes * 3,329 MW/T = 6102.1MW pr. Day

Average energy consumption of Accra Brewery daily = 9475 kWh or 9.475 MWh per day.

Therefore, Accra Brewery needs 9.475/6102.1 = 0.037 or 3.7% of the total waste generated.

4.1.5 Choice of Technology

All the analysis carried out above gives an indication of success by using moving grate incinerator which has conformed to the characteristic of waste generated in the study area Accra. To provide efficient and effective generation of heat to Accra Brewery limited. This technology is used by municipalities and large industrial plants. The design has an operating capacity of 354 days and 8500 hours per year, and can handle up to 35 metric tonnes waste per hour.

The amount of 21,996 tonnes per annual will be incinerated, an economic evaluation for building the WtE plant for the company will includes the following, investment or capital costs for construction as well as running costs for operation and maintenance of the plant. Features and capacity of a moving grate incinerator.

Table 3. Features and capacity of a moving grate incinerator

KILN-1,25	1.250.000 Kcal/h	(1.164 kW)	218 kg/h	326 kg/h	150 kg/h
KILN-2,5	2.500.000 Kcal/h	(2.910 kW)	436 kg/h	654 kg/h	300 kg/h
KILN-3,75	3.750.000 Kcal/h	(4.365 kW)	654 kg/h	981 kg/h	450 kg/h
KILN-5	5.000.000 Kcal/h	(5.820 kW)	872 kg/h	1308 kg/h	600 kg/h
KILN-7,5	7.500.000 Kcal/h	(8.730 kW)	1308 kg/h	1962 kg/h	900 kg/h
KILN-9	9.000.000 Kcal/h	(10.477 kw)	1569 kg/h	2354 kg/h	1076 kg/h
KILN-11	11.000.000 Kcal/h	(12.800 kW)	1918 kg/h	2877 kg/h	1315 kg/h
KILN-20	20.000.000 Kcal/h	(23.273 kW)	3487 kg/h	5231 kg/h	2391 kg/h

4.2 ECONOMICAL EVALUATIONS

Table 4 below shows a monthly expenditure carried out to determine how much the company spends on running the existing plant, in other words to estimate the payback period of the new technology (waste incineration), there is a need to consider the consumption pattern of boiler plant.

The calculations are based on, how many liters of fuel is consumed per day and the total consumptions per month as well as fuel consumptions in mega joules to determine how many tonnes of waste per calorific value and the respective heat content would need to generate the steam. The amount of GH¢ (8455137, 808) was obtained during the monthly run down of cash which translate to (€ 1936161.73). To calculate the running costs of the plant for a year, it is possible to multiply the total amount for a month by twelve months since the plants runs 24/7 throughout the year. Tables 5 and 6 below shows the operational and maintenance costs of the boiler plant and waste incineration plant.

Table 4. Monthly operational data of ABL

Days	Fuel Consumption in Liters/day	Fuel Consumption in Mega Joules (MJ)	Quantity of Steam Produced (KJ/kg)/da	Price/liter (2.84 Gh¢) Exchange rate 1€=4.37ghc Gh¢	€
1	5457,6	203568,48	62037	15499,584	3549,29
2	4521,6	168655,68	348349	12841,344	2940,57
3	6648	247970,40	20428	18880,32	4323,45
4	8569,2	319631,16	83997	24336,528	5572,88
5	4395,6	163955,88	56189	12483,504	2858,63
6	5912,4	220532,52	62234	16791,216	3845,06
7	8552,4	319004,52	79599	24288,816	5561,95
8	7982,4	297743,52	75770	22670,016	5191,26

9	6912	257817,60	65354	19630,08 4495.14
10	5757,6	214758,48	50418	16351,584 3744.39
11	8778	327419,40	84886	24929,52 5708.67
12	7488	279302,40	65790	21265,92 4869.73
13	5174,4	193005,12	52001	14695,296 3365.11
14	9046,8	337445,64	87186	25692,912 5883.48
15	8612,4	321242,52	88072	24459,216 5600.97
16	3392,4	126536,52	29510	9634,416 2206.21
17	10912,8	407047,44	93114	30992,352 7097.01
18	9361,2	349172,76	62053	26585,808 6087.95
19	11185,2	417207,96	120246	31765,968 7274.16
20	10744,8	400781,04	114870	30515,232 6987.75
21	10594,8	395186,04	104681	30089,23 6885,41
22	11100	414030,00	98036	31524,02 7218.75
23	14500	540850,00	70304	41180,43 9429.9
24	11800	440140,00	132587	33512,76 7673.99
25	13800	514740,00	154904	39192,54 8974.67
26	19400	723620,00	132348	55096,81 12616.56
27	15700	585610,00	95049	44588,38 10210.31
28	14432,4	538328,52	85965	40988,016 9385.94
29	13617,6	507936,48	75721	38673,984 8856.05
30	11840,4	441646,92	55948	33626,736 7700.26
31	15859,2	591548,16	97252	45040,128 10313.84
TOTAL	No: of litres 302049.2	11266435,16	2804898	Gh¢= 857819.728 €= 196297.4206

Table 5. Yearly operational and maintenance costs of ABL boiler plant

Yearly Operational and Maintenance Costs of Boiler Plant. Currency = Gh¢.	
Operation Costs	
Administration and salaries	10000000
Nos of Staffs (5) with 1500 Gh¢. each	90,000
Fuel Cost	10293835.66
Total Cost	10383835.66
Maintenance Cost	
Fuel Filters	700
Oil Pump	1400
Valves	1000
Boiler Roding	700
Miscellaneous Cost	650
Total Cost	4,450
Total O&M Cost	10388285.66 Gh¢. 2,377,182 €

The yearly operational cost of the incineration plant includes Administration and salaries, cost of materials needed for air pollution control, human resources, cost for amenity and office maintenance, and other administrative costs excluding maintenance cost.

Table 3. Yearly Operational and Maintenance Cost of Incineration Plant.

Yearly Operational and Maintenance Cost of Incineration Plant.	Currency = €
Administration and salaries	10000000
Nos of Staffs (3) with 1500 Gh¢/month. each	12,356.95
Nos of Automated engineers (3) with 3000 Gh¢/M. each	24,713.95
Cost of Gas Cleaning.8% of Investment Cost (10 M)/yr.	800,000
Cost of Residual Disposal. 2% of Investment Cost (10M)/yr.	200,000
Total	1,037,069
Maintenance Cost	
Overall maintenance Cost. 1% of Investment Cost (6 M)	100,000
Total O&M Cost	1,137,069 €

4.2.1 Payback Calculations

The capital investment cost (CAPEX) of the waste incineration plant is estimated to an amount of 10,000,000 Euros, that includes the following parameters, plant capacity, costs of all individual components, waste transportation facilities, shipping cost of the components, goods clearing at the harbor, construction costs and other miscellaneous costs.

The estimated operational and maintenance costs (OPEX) of both waste incineration plant and the existing ABL boiler plant will be considered to determine the savings and the payback time of the incineration plant.

Investment costs: 10,000,000 €

The operational and maintenance cost of the waste incineration plant: 1,037,069 €

The operational and maintenance cost of the existing ABL boiler plant: 2,377,182 €

Savings = 2,377,182 - 1,037,069

=1,340,113 €

Payback time $= \frac{investment\ costs\ of\ the\ plant}{savings}$,

Therefore, P.T$= \frac{10{,}000{,}000}{1{,}340{,}113}$ = 7, 5 years.

The calculation above gives a clear indication that running the existing ABL boiler plant costs the company heavily.

Therefore, shifting from the boiler plant to municipal solid waste incineration plant will help the company to save a lot of money. This is based on the payback time of the waste incineration plant that comes between 7.5 to 8 years and the fact that the life cycle of the plant is 20 years. If the company invests in waste incineration, it will get approximately 12 years operational profit from the plant.

The waste incineration plant capacity calculations were determined by using boiler capacity shown in Table 4 above that gives the monthly operational data of Accra Brewery limited. The capacity of the plant (9.475 MW) was determined by calculating the average of steam (kJ/s) generated in a month.

5. CONCLUSIONS

The outcome of the research has proven that municipal solid waste incineration for Accra Brewery limited will be profitable based on the analysis carried out in Chapter 4. The waste composition in Accra indicates that 1,833 tons of waste is generated daily that corresponds to 6102.1 MJ/kg of energy. The size of the waste incineration plant was 9.5 (MW) that will provide a quantity of 33,658,776 kJ/kg of steam for yearly production. However, the analysis shows that there is a high potential for waste incineration plant due to the volume of the waste generated yearly at the disposal site.

It is important to stress that the waste incineration plant reduces a large percentage of waste generated 60%. Therefore, it will help to improve the environmental performance of waste management systems that Accra has been challenged with.

This study analyses between the existing boiler plant and waste incineration and it has shown that with present conditions, it is economically beneficial for Accra Brewery to invest in a waste incineration plant since it has a greater profit.

5.1 Suggestion for Further Research

The findings available suggest that further research can be taken for Ghana as a whole to determine the waste compositions widely and to implement a large capacity waste incineration plant to support electricity demand and help to manage the waste system.

If the waste incineration technology would not be economically beneficial it might render some usefulness, such as waste percentage reduction, reduction of flooding, elimination of diseases (cholera, malaria, chicken pox).

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APPENDICES

APPENDIX 1. Generation and Composition of Sub-Fractions of Household Wastes from Accra /1/.

Compositions	High class income areas			Middle class income areas			Low class income areas		
Organic	Total waste /kg	% composition	Per capita/kg/p/day	Total waste/kg	% composition	Per capita/kg/p/day	Total waste/kg	% composition	Per capita/kg/p/day
Food waste	12110.1	44.201	0.235	13777.2	50.959	0.236	13752.5	49.358	0.220
Yard waste	4749.3	17.334	0.092	2058.2	7.562	0.035	2484.1	8.915	0.040
Wood	356.3	1.301	0.007	366.5	1.346	0.006	357.1	1.282	0.006
Animal	48.3	0.176	0.001	103.1	0.379	0.002	81.2	0.291	0.001
Paper and cardboard									
News paper	184.6	0.674	0.004	105.7	0.388	0.002	115.4	0.414	0.002
Office Print	165.8	0.605	0.003	121.2	0.445	0.002	150.6	0.541	0.002
Tissue paper	314.6	1.148	0.006	413.8	1.520	0.007	467.3	1.677	0.007
Cardboard/packa	883.0	3.223	0.017	875.5	3.215	0.015	622.2	2.233	0.010
Non-biodegradables									
Plastics									
Plastics	567.4	2.071	0.011	988.0	3.628	0.017	1492.9	5.358	0.024
PET	908.2	3.315	0.018	897.9	3.297	0.015	568.1	2.104	0.009
HDPE	842.5	3.075	0.016	749.2	2.751	0.013	952.2	3.418	0.015
PP Rigid	425.8	1.554	0.008	414.1	1.521	0.007	313.6	1.126	0.005

PS	166.1	0.606	0.003	146.6	0.538	0.003	162.4	0.583	0.003
PVC	151.7	0.554	0.003	168.4	0.618	0.003	68.7	0.247	0.001
Other plastics	658.0	2.402	0.013	539.9	1.983	0.009	599.9	2.153	0.010
Metals									
Scraps metals	290.4	1.060	0.006	428.9	1.575	0.007	147.7	0.530	0.002
Cans/tins	471.6	1.721	0.009	359.3	1.319	0.006	587.4	2.108	0.009
Glass/bottles									
Coloured	784.7	2.864	0.015	542.2	1.991	0.009	395.6		0.006
Plain	231.8	0.846	0.004	292.0	1.072	0.005	163.8	0.588	0.003
Leather & rubber	177.3	1.012	0.005	318.9	1.171	0.005	288.5	1.035	0.005
Textiles	144.6	0.528	0.003	312.8	1.149	0.005	501.3	1.799	0.008
Inert(Sand, ash,	1021.6	3.729	0.020	1584.1	4.817	0.027	2473.3	8.877	0.040
Miscellaneous or	1644.1	6.001	0.032	1665.8	6.117	0.028	10981.1	3.941	0.018
Total	27397.8	100.000	0.531	27230.1	100.000	0.466	27862.8	100.000	0.446