# ELECTRICITY GENERATION POTENTIAL FROM MUNICIPAL SOLID WASTE IN UYO METROPOLIS, NIGERIA

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MATRIC. NO.: 142347

A thesis in the Department of MECHANICAL ENGINEERING

Submitted to the Faculty of Technology in partial fulfillment of the requirements for the award of the Degree of

Doctor of Philosophy

of the

UNIVERSITY OF IBADAN, IBADAN

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MARCH, 2019

**ABSTRACT**

Disposal of Municipal Solid Waste (MSW) has been identified as a major environmental challenge in developing countries. Electricity generation has been identified as one of the ways for utilisation of MSW. Literature is scanty on the characterisation of MSW for optimal electricity generation in Nigeria. This study was designed to investigate the potential of electricity generation from MSW in Uyo metropolis, Nigeria.

Municipal solid waste of 100 kg were collected from ten selected sites in Uyo metropolis and segregated into eight components. Data for the estimation of total volume of MSW were collected through field studies and AkwaIbom State Waste Management and Environmental Protection Agency, and spot sampling method was used to sort the MSW. Calorific Values (CV) of the segregated MSW components: Organic Waste (OW); Paper-Carton Waste (PCW); Plastics Waste (PW); Textile, Leather and Wood Waste (TLWW); Glass Waste (GW); Iron and Metal Packaging Waste (IMPW); Inert Metal Waste (IMW); and Unknown Waste (UW), were determined using bomb calorimeter at 10% moisture content. A prototype power plant of 1 kW capacity was designed and constructed according to standard procedures to model electricity generation from MSW using two sets of 42 combinations of two and three ratios of segregated components based on literature. The first combination consisted of six different mix of PW/TLWW, PW/OW, PW/PCW, TLWW/OW, TLWW/PCW, and O/PW, across five different ratios (9:1, 8:2, 7:3, 6:4 and 5:5); while the second consisted of four different mix of PW/TLWW/OW, PW/TLWW/PCW, PW/OW/PCW, and TLWW/OW/PCW across three different ratios (5:4:1, 5:3:2 and 4:3:3). Linear programming model was used to obtain the CV of the mix and Dulong equations were used to determine the electricity potential of MSW. Data were analysed using ANOVA at $\alpha_{0.05}$.

The estimated annual volume of MSW was 72,000 tonnes for a population of about 847500. The components were dissagregated into 66.3% OW, 18.4% PCW, 5.2% PW, 4.3% TLWW, 1.3% GW, 2.1% IMPW, 0.5% IMW, and 1.9% UW. The CV of the components obtained for OW, PCW, PW, TLWW, GW, IMPW, IMW, and UW were 18.0, 17.0, 40.0, 32.0, 0.0, 0.0, 0.0, and 18.0MJ, respectively. The CV of PW/TLWW, PW/OW, PW/PCW, TLWW/OW, TLWW/PCW, and OW/PCW at 9:1 mix were 39.20±0.70, 37.80±0.63, 37.70±0.43, 30.60±0.71, 30.50±0.57, and 17.90±0.68 MJ, while at 6:4 mix, the CV were 36.80±0.81, 31.20±0.56, 30.80±0.21, 26.40±0.45, 26.00±0.44, and 17.60±0.42 MJ, respectively. The CV of PW/TLWW/OW, PW/TLWW/PCW, PW/OW/PCW, and TLWW/OW/PCW at 5:4:1 mix were 34.60±0.54, 34.50±0.53, 28.90±0.35, and 24.90±0.32 MJ, while at 4:3:3 mix, the CV were 31.00±0.69, 26.50±0.55, 26.50±0.45, and 23.30±0.46 MJ, respectively. The estimated power potential ranged from 5.0 to 8.0 MW. The highest potential was obtained for PW/TLWW ( 9:1), while the lowest potential was obtained for OW/PCW (5:5) operating at 160.93 tonnes/day. There was no significant difference between the estimated power potential and the published data for same mix ratios.

The use of municipal solid waste for electricity generation is feasible in Uyo metropolis. Improved waste mix of plastics, textiles, wood and leather gave the highest electricity generation potential.

**Keywords:** Waste characterisation, Municipal solid waste, Energy potential
**Word count:** 496

**ACKNOWLEDGEMENTS**

Many thanks to God for His grace throughout the challenging duration of this programme. I most grateful to my project Supervisor, Dr.Chukwuemeka Jude Diji for his wonderful understanding and contributions in completing this study. My utmost appreciation also goes to the Head of Department, and all staff, teaching and non-teaching of the Mechanical Engineering for their support and understanding throughout this programme.
Special thanks goes to the postgraduate coordinator of the Department of Mechanical Engineering, Dr. Abu, Sub-Dean Postgraduate of the Faculty of Technology, Dr. A.A. Olapade, Dr. Dare, Dr.Ajude, etc. My thanks equally goes to my special colleagues, Engr. Comfort Adadu, Dr. Isaac William, Engr. Ogunleye, Engr. Bassey, Mr. Dennis Edem, Basil Ebiang, etc.

My wife Mrs. Edoama Dominic Ekpo had been in total support of this programme in all ramifications. God in heaven will continue to reward her and favour her like Esther in the Bible. To my immediate elder brother, Mr. Solomon Ekpo, the initiator and major sponsor of this programme, who encouraged me financially and morally but could not complete it due to the cold hand of death. May his soul rest in peace.
I am indebted to my beloved mother, Mrs. Sabbath David Ekpo for her moral and financial support. Also, I express my gratitude to my elder brothers and sisters who in their prayers, made it possible for this work to be completed. Mr. Isang David Ekpo, Mrs. Grace Francis, Mrs. Iniobong John Cyril, Mr. Samuel Ekpo, etc. My good friends like Mr. EmanaEdem, Dr. Henry Johnson, BasseyNkanang, etc. are equally appreciated.

In all, I thank you all in your encouragement and advice. May God bless you abundantly in Jesus Name. Amen.

**CERTIFICATION**

I certify that this work was carried out by D. D. Ekpoin the Department of Mechanical Engineering, University of Ibadan, Ibadan.

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## NOMENCLATURE

Municipal solid waste- MSW

Calorific value- CV

Integer linear programming- ILP

Municipal Solid waste mix- MSWM

Plastic waste/textile, leather, wood waste-PW/TLWW

Plastic waste/organic waste-PW/OW

Plastic waste/paper-carton waste-PW/PCW

Textile, leather, wood, waste/organic-TLWW/OW

Textile, leather, wood/paper-carton-TLWW/PCW

Organic waste/paper-carton-OW/PCW

Plastics/Textiles, leather, wood waste/Organic waste- P/TWL/O

Plastics, Textiles, leather, wood/Paper-carton- PW/TLWW/PCW

Plastics/Organic/Paper-carton- PW/OW/PCW

Textiles, leather, wood waste/Organic waste/Paper-carton waste- TLWW/OW/PCW

Organic waste-O

Textiles, Wood, Leather- TWL

Paper- Carton-PC

Plastics-P

Metals- M

Glass-G

Inert Matter-IM

Others-OT

Mega joules- MJ

# CHAPTER ONE

# INTRODUCTION

## 1.1 THE HISTORY OF POWER GENERATION IN NIGERIA

The electricity generation and distribution started in 1895. In 1929, the Company was later founded as NESCO. That is Nigeria Electricity Supply Company. It operated as a utility company in Jos. In 1951, the Electricity Corporation of Nigeria (ECN) was founded. This was followed by setting up of the first 132KV line. This was built in 1962 to link Ijora to Ibadan power station (Nigerian Electricity Regulatory Commission 2007)

According to Nigerian Electricity Regulatory Commission, 2007, "Since then, there have been an increasing electricity infrastructure and changes both in the nomenclature and operations of the regulatory agencies like, the establishment of The Niger Dams Authority (NDA) established in 1962 with a mandate to develop the hydro-power sub-sector and the subsequent merging of Niger Dams Authority with Electricity Corporation of Nigeria in 1972. The National Electric Power Authority (NEPA), the current National Electricity Regulatory Commission (NERC) and Power Holding Company of Nigeria (PHCN) followed afterwards as the search for stable and affordable power supply in the country continues. At the moment, Nigeria generates about 5000 MW of electricity for its population of more than 160 million people. This is saddening and embarrassing when compared to a country like South Africa that generates over 40,000 MW for its population of 52 million**.**

Of recent, Government has initiated efforts and reforms to improve electricity supply. Of recent, are the "Electric Power Sector Reforms Act of 2005' and the subsequent 'Power Sector Reform Roadmap' initiated in 2010 by the Jonathan's administration. The Power Sector Reform Roadmap was meant to unbundle the electricity sector chain and promoting a private sector-led electricity sector also encompasses issues of electricity pricing and regulatory frameworks**.** Its aims to generate 40,000 MW of electricity by 2020 while expanding generation and transmission capacity and also improving the market structure" (Presidential Task Force on Power, 2015). This process did not take into consideration what generation technology and capacity is to be added. It recommendations were mainly on expanding generation capacity through hydro and gas power plant and it did not consider a holistic energy mix for power generation expansion. This is as proven as most ongoing and some newly completed power generation expansion project developed under the National Integrated Power Project (NIPP) are mainly gas and hydro power plant. Independent Power Producers (IPP) has also followed suit, there by leaving other power sources such as wind, nuclear, coal and the use of municipal solid waste untapped. It is of recent, that Nigeria Atomic Energy Commission (NAEC) has entered talks with Rosatom Corporation. This is a Russian Company to construct a 4800MW nuclear power plant under the build, own, operate and transfer Board of Trustees (BOT) agreement at a cost of US$ 20billion (Presidential Taskforce on Power 2015) . It is expected that preliminary licensing of the approved sites by the Nigerian Nuclear Regulatory Authority (NNRA) is expected by the end of year 2016 (Presidential Taskforce on Power 2015).

## 1.2 WASTE

According to World Health Organisation, "Waste is defined as any material lacking direct value to the producer and so must be disposed of. It alsorefers to waste as "something, which the owner no longer wants at a given time and space and which has no current or perceived market value". "This idea and perception of represented a broad-based approach toward the classification of what really constitutes waste" Barraclough, 1993. Barraclough also classified wastes "as gaseous, liquid, or solid. Gaseous and liquid wastes are known to be free flowing and can easily migrate from one place to another, whereas solid wastes are not free flowing, their flow is only influenced by human activities. Handling and containment of gaseous, liquid and to greater extent solid wastes has been known to be one of man's intractable problems**.** Indiscriminate disposal and dumping of refuse has become a common practice and almost a normal tradition in Nigerian cities. Most of the waste dumps are located very close to where human beings are residing, roadsides, markets, farms, creeks, etc. The composition of waste dumps varies widely, with the type of human activities taking place around the dumpsites. Close examples of these activities include domestic, commercial and industrial wastes. The presence of municipal solid wastes reduces the aesthetic value of the environment and also make way for various diseases and toxic conditions inherent in and derivable from wastes products".

### 1.2.1 TYPES OF WASTES

Kumar, et al, 2016, described waste materials as "waste stream which includes the entire variety of refuse generated during industrial, domestic, commercial and construction processes. Depending on the base in which the waste was derived, the refuse varies from country to country. In most of the developed countries especially, the western communities, the major components derived from industrial waste are steel slag, blast furnace and electrical power station ash".

"Industrial wastes are waste generated from industrial activities like, chemicals, paints, pesticides, oil sludge, grease, inorganic materials, etc. Domestic wastes are the type of waste generated from household activities and commercial establishments. These waste appear in different forms, ranging from water-borne waste emanating from households, including sludge water and sewage, rubbish items, animals and human remains as well as laboratory and wastes" (Kumar, et al, 2016).

The major focus of this work is on MSW.

### 1.2.2 MUNICIPAL SOLID WASTE (MSW)

This can be described as unwanted products that are generated by people in the environment (Alfred, 2015). It is the refuse generated from urban centres, markets and houses, etc. (Alfred 2015). Waste stream, that range from paper, carton, plastics and organic waste of different types constitute the major components of MSW (Renewable Waste Intelligence, 2013).The constituent of MSW varies meaningfully from one country to the other. It mostly changes with time (Sule, 2004).In the western countries and America, that have a better recycling technology, the waste component constitute mostly of intractable MSW such as un-recyclable packages (Sule, 2004). In advanced communities, in the absence of better recycling, it involves mostly refuse from food and other types of refuse (Ekugo, 1998) .

Municipal Solid Waste is classified in several ways which include the following:

- Wastes that are biodegradable: These type of wastes includes kitchen waste, paper, food waste and green waste (Kumar, et al 2016).
- Refuse that can be recycled: These type of refuse includes irons, books, containers, wears, certain rubbers and etc. (Kumar, et al 2016).

- Inert Waste materials: These type of wastes includes demolition waste and construction waste, dirt, debris and rocks (Kumar, et al 2016)
- Electronic refuse materials. These type of refuse materials includes electrical and electronic refuse materials, etc. (Kumar, et al 2016)
- Composite wastes materials: These type of waste materials includes waste clothing, waste plastics, Tetra Packs (Kumar, et al 2016).
- Hazardous refuse materials. These type of refuse materials include paints, chemicals and agricultural additives (Kumar, et al 2016).
- Wastes that are toxic: These type of waste materials includes herbicides, pesticide and fungicides (Kumar, et al 2016).
- Medical waste materials: These include waste derived from hospitals like the expired drugs and etc. (Kumar, et al 2016).

## 1.3 MANAGEMENT OF MUNICIPAL SOLID WASTE

The main steps applicable in the management of MSW are the generation, sorting, separation, transfer and discharging processes. The process going this way, after the disposal of the MSW, it can now be used in any of these four ways, which include recycling, landfilling, composting and waste-to-energy through incineration (Agunwamba, 1998).

The functional element of collection of MSW includes but not limited to the collection of MSW and recyclable particles, but also involve the transportation of these particles to the point where the vehicles carrying the collected MSW are discharged. This point could be a waste processing plant. It could also be a transfer station. At the same time, could be a landfill discharging point (Agunwamba, 1998).

According to Ekugo, 1998, "Waste handling and separation are important activities related to municipal solid waste management till the municipal solid waste are placed in storage containers for collection. Handling of the waste also involved the movement of these loaded containers to the point of collection of the municipal solid waste. Most tedious process of MSW involves separation of MSW from dumpsite. Presently, curbside collection, drop off and buy back centres are the means and facilities for the recovery of municipal solid waste materials that have been separated from the source. The separation and processing of municipal solid waste which have already been separated at the source and the separation of other commingled wastes mostly take place at the materials recovery facility, transfer stations, combustion facilities and also disposal sites".

Alfred, 2015, also explained that "the transferring and transportation of municipal solid waste involves two major processes; firstly, the waste is being transferred from a much smaller collection vehicle to much larger transportation equipment. The municipal solid waste dumped is now transported, which normally take long distances, to a processing or disposal site"

The modern landfill for disposal of MSW is not a dumpsite. Nowadays, they are engineering system used for disposal of MSW on land which does not develop or create nuisance or contamination to the environment. Environmental health and safety are taken into consideration (Sule, 2004).

MSW can be used extensively for electricity generation (Ekugo, 1998). Several technologies of MSW have been designed. This help in the processing of MSW for power production. The system is better compared to the ones that were in existence.

The technology incorporate the following:

- Landfill gas capturing.
- Combustion.
- Pyrolysis.
- Gasification.
- Plasma arc gasification ( Ekugo, 1998)

In this study, MSW is considered a major source of material for generating electricity in Uyo metropolis, a major state capital in the south – south part of Nigeria.

## 1.4 ENERGY FROM WASTE

Waste energy in its practical deployment, features the development of municipal solid waste combustion plant, is in various stages of progress for most of these countries (Hollenbaccher, et. al, 1973). At the moment, Austria is the leading country in the generation of energy from municipal solid waste field in Europe, presently having several units in operation, which utilise the local municipal solid waste effectively. The rest of the larger cities follow in a steady pace (Munster, 2009).

## 1.5 WASTE TO ENERGY PLANTS

There are two identical configurations of municipal solid waste to energy plants, which are designated differently according to their characteristics and method of operations. They are RDF and combustion system (Rotter, 2011). The major difference in these operations is one characteristic element, which takes place before municipal solid waste is being combusted (Hulgaard and Vehlowy, 2011). In the case of a refuse derived fuel, plant separation of non-combustible particles is undertaken by shredding the municipal solid waste (Rotter, 2011. One of the most appreciable aspects of refuse derived fuel is that it can be employed as a supplementary fuel in conventional boilers, the other aspect involved burning unprocessed MSW directly in the incinerator. This burning procedure happened in a control input of air (Bain, et. al, 1996).

## 1.6 PROBLEM STATEMENT

Low energy output has cause many challenges in AkwaIbom State to a great extent, even with the support of (IPP) in IkotAbasi. Presently, the state government is trying to change the orientation of the people from civil mentality to an industrialized one as this requires a better power supply to accommodate the investors. Presently, the quantity of MSW in the state is on a high increase and there is need to convert waste to energy.

This study of MSW for electricity production in Uyo metropolis involves the process of sorting and combination of waste in two or three optimum mix in order to get the best optimum mix of MSW for electricity. The type of MSW that have been identified in Uyo metropolis include; Organic, paper-carton, Textiles, wood, leather, Plastics, metals, glass, inert matter and others.

In summary, the study intends to address the following problems;

- ❖ There is need to improve energy supply in AkwaIbom State.
- ❖ This energy is needed to accommodate the investors to industrialized the state for commercial activities
- ❖ Presently, the quantity of MSW in the state is of large quantity and can be converted to electricity.
- ❖ This study is based on the utilization of municipal solid waste for power generation in Uyo.
- ❖ The study models various combinations of municipal solid waste that will give a better optimum energy.

- The model of the municipal solid waste plant proposed involves the sorting of waste and selection of the optimum mix in two and three combinations for electricity generation**.**

## 1.7 OBJECTIVES OF THE STUDY

- Determine the total quantity of MSW generation in Uyo metropolis.
- Characterization of the MSW composition in Uyo metropolis.
- Energy output from each of the waste composition.
- Developing a model to ascertain which of the waste combination will give a better energy output taking into consideration the quantity of MSW.
- Determining the electricity potential of MSW in Uyo

## 1.8 PROJECT GOAL

This research is to propose the establishment of a waste – fired power plant as a sustainable metropolitan MSW management system that utilizes MSW to generate electricity and improve the environment in Uyo metropolis of Akwa Ibom State, Nigeria.

## 1.9 SPECIFIC AREA OF RESEARCH

This research shall focus on the utilisation of MSW for electricity generation in Uyo metropolis of Akwa Ibom state, Nigeria.

## 1.10 BRIEF DESCRIPTION OF THE CITY OF UYO

Uyo is a town in southern geopolitical zone of the country. It is the centre of government in the state. The state is one of the highest producers of crude oil in the country. It was created in September 23, 1987. It has a federal University residing in the metropolis. It has a population of approximately 900, 000 people from statistics. The city has a very good road network and well plan to reduce traffic and unnecessary flooding. It has a cargo airport which up-to-date in their operation. The city is developing very fast due to high influx of investors to the state as the present government is bent on industrialization. Presently, there good roads constructed for minimization of hold-up in the city. The town is habitable with the high level of security and low menace of arm robbery incidents. The city has good hotels for quick accommodation of the foreign investors. There are lots of developmental projects that are ungoing which makes it more habitable for both the indigenes and the foreigners (http:akwaibomstate.gov.ng).


Plate 1.1 MAP OF AKWA IBOM STATE SHOWING THE CITY OF UYO

# CHAPTER TWO

# REVIEW OF RELATED LITERATURE

## 2.1 WASTE MANAGEMENT

Waste management can be explained as the procedure of obtaining utilization of waste materials (Adegoke, 1989). This particular definition is mostly associated to with large particles from human being for minimization of environmental issues. Waste management is a process that is carrying out to reduce and to recover some good resources during the process (Adegoke, 1989). This refuse management consists of all types of waste. It also involves radioactive substances and the inert matter. The process of refuse management differs from place to place, time and how exposed the place is and the awareness (Ahsan, 1998). This management of refuse should be the concern of everybody. That is government and individuals.

## 2.2 PROBLEMS OF INADEQUATE WASTE MANAGEMENT

This management in Nigeria has so many issues, these problems range from environmental, economic to sociocultural problems (Adegoke, 1989). It is sad, the level of awareness and environmental awareness, a sort of orientation associated to hazards of contaminated environment is very low. More attention by people are given on how to survive and not giving attention related on the orientation of waste management (Adegoke, 1989).

"At the urban centres level, poor management skills in the handling and disposal of domestic waste are also the major issue. Under this circumstance, most of the government technocrats encourage open dumps as the option of waste-disposal process. In most cases, these dumps site are situated where land is available without taking into consideration, the health hazards, safety, and also on the aesthetic values of the place. In some cases, the waste is dumped and when dried allowed to be ignited and burn gradually in the open" (Alfred, 2015). "Due to the varied/complex nature of the wastes, this practice introduces hazardous combustion products into the atmosphere which may not be habitable to the populace. Notable among these products

Sulphur dioxide, carbon monoxide, halogenated carbons, oxides of nitrogen, particulate of matter and the hydrocarbons. Moreover, the low level of financing the agencies which are responsible for handling and disposal of these waste in Nigeria has to a very big extent affected the performance and the outcome of these agency" (Agunwamba, 1998). They tend to get very little revenue or finances from the populace as very few people are served with this house to house services. Property taxes and tenement rates are not collected at all times. Authorities responsible for handling and disposal of waste-management should make efforts not to depend on government subsidies, which does not come at the right time (Ekugo, 1998).

It is known that the population of our country, Nigeria is continuously at the increase, as such the waste generated is affected by this increase. "As such, high levels of industrial development and concentration of major government establishments in the urban centres has resulted in the influx of people from the rural environment to the urban centres. Building of accommodation results in the indiscriminate construction of shanties and substandard housing without regard to the authority of the urban planning which minimizes the efficient town planning for the collection, handling and the disposal of waste" (Adegoke, 1989).

"It is only recently that the AkwaIbom State Government contracted refuse collection and disposal to waste-disposal companies, which are doing well to reduce the menace of waste management. These companies, however, cannot adequately take care of solid-waste management, as some of the municipal areas are not included and the methods of refuse collection not always adequate. For instance, these companies use shovels and open trucks, which leave droppings from wastes along the streets. Also, sorting the waste at the point source is not fully addressed. This effort by government could be better planned and expedited to ensure wider coverage and more effective participation by the people" (AkwaIbom State Waste Management and Environmental Protection Agency, 2013).

"In Uyo, cases of illegal development of squatter settlements along the waterfronts without regard to urban development regulations abound. Basic infrastructure like adequate water supply and waste-disposal systems are virtually absent in these settlements. Due to low rent and substandard accommodation, these settlements are usually grossly overpopulated. Household and human wastes are often disposed directly into the water body or simply dumped along the streets, contributing substantially to environmental pollution, and health problems" (AkwaIbom State Waste Management and Environmental Protection Agency).

## 2.3 CHALLENGES OF URBAN WASTE MANAGEMENT

Studies from AkwaIbom State Environmental and Waste Management Agency shows that, the issues, conditions and problems of MSW management in the industrialized and civilizing countries are different from our society here in our country, Nigeria, AkwaIbom State and Uyo metropolis in particular. Though it is a clear case that the developed countries generate more quantity of MSW and have resulted to developing a better facilities which has competent government institutions and bureaucracies to address and manage their municipal solid wastes. Developing countries in Africa, example Nigeria are still in the transition process towards a better municipal solid waste management but they are currently having problem of insufficient collection and issue of disposal of these municipal solid waste. In these part of the world, services and programmes that incorporate proper MSW disposal for proper management of hazardous biological and chemical wastes, reduction and recycling will be of utmost important. All these process have different degrees of negative environmental interpretations with adverse health risks and environmental factors if municipal solid wastes are not properly disposed or kept safe (Adedibu 1983).

### 2.3.1 Challenges of Municipal Solid Waste Management in Uyo Metropolis

At the municipal level, Uyo Township in particular, inadequate process in the management is a major issue. Lack of funds, also, is a major challenge in the management of MSW (AkwaIbom State House of Assembly second quarter proceedings, 2011). At the state government level, in 2009, the state government had a budget of N195.3 billion in which N7.807 billion was allocated for environment forming about 4% of the total budget for the state (AkwaIbom State House of Assembly second quarter proceedings, 2011). In 2010, a total of N384.8 billion was the budget and only N53.744 billion was allocated for environment forming just about 14% of the total budget in 2011(AkwaIbom State House of Assembly second quarter proceedings, 2011). The figure above has been a continuous process till 2015 which does has significantly affect the proper management of municipal solid waste (AkwaIbom State House of Assembly second quarter proceedings, 2011).

## 2.4 MUNICIPAL SOLID WASTE POWER PLANTS

MSW plant has being one of the most pronounce waste-to-energy technologies in the world. MSW can be burnt in this type of facility to produce energy with less processing. This process is known as mass burn. There are lot of ways in which the municipal solid waste can be process. These include direct combustion as refuse-derived fuel, by gasification process, pyrolysis and by anaerobic digestion (Albert, 1972).

All these processes of municipal solid waste application have the opportunities for landfilling, composting and for electricity generation. MSW plant is somehow cheaper, in the sense that considering other energy technologies in which the fuel supply have to be purchased, the waste to energy plant using municipal solid waste, the suppliers of the fuel which is municipal solid waste have to pay for their fuel to be evacuated (Bain, et. al, 1996). "Municipal solid waste-to-energy technology, like landfill gas recovery, allows electricity production from already existing landfills through the process of natural degradation of municipal solid waste by anaerobic fermentation also known as digestion into landfill gas. In most of the urban areas, municipal solid waste sludge is commonly used for the process of anaerobic digestion" (Mashavu, et al, 2001).

### 2.4.1 Mass Burn (Incinerator)

Mass burn technology is also known as incineration. This is the most common municipal solid waste combustion technology. It involves the combustion of unprocessed or less processed MSW for energy generation (Hulgaard T. and Vehlowy, 2013).

The major components of a mass burn facility are listed below"

- "Refuse receiving component, handling and storage facility.
- The combustion chamber and steam generation system that is incinerator and a boiler.
- An exhaust gas cleaning system.
- The combined power generation facility that is a steam turbine and a generator.
- A condenser for cooling system.
- A residue or ash hauling and storage system" (Mashavu, et al, 2001).

“The process of incineration start from where the incoming trucks carrying the municipal solid waste drop the waste into pits, then cranes mix the waste to remove bulky or large non-combustible items, then the waste storage area are maintained under pressure which is less than atmospheric pressure in order to prevent odours from escaping to the ambient. The cranes move the waste to the combustor-charging hopper for the purpose of feeding the incinerator” (Mashavu, et al, 2001).

The heat generated from the incineration system is now applied for steam production from the water in the boiler, the steam now channelled to a steam turbine generator for electricity production (Feldmann, 1973). The steam can now condensed through traditional method and channelled back to the boiler, a sort of economizer which increase the efficiency of the system. “Residues produced include ash below the bottom of the combustion chamber, fly ash which comes out from the combustion chamber with the flue gas a very high temperature combustion products” (Hollenbacher, 1992).

This ash residue that are available sometimes are hazardous and sometimes are not hazardous. This varies on the type of the MSW used. The best way to prevent the hazardous ash from being produce is by preventing the source of the MSW that is to be use. Another way is by treatment of the ash. These two methods divert high costs of processing of MSW in the landfills which is a centre in the handling of hazardous municipal solid waste but it increase the cost of this incineration process. It is also known that non-hazardous ash produced can also be mixed with soil for some agricultural purposes and for some civil engineering process like pavement aggregate (Boerrigter, 2002).

**Permitting Issues for Mass Burn Facilities**

There are some conditions that affect mass burn facilities and this include (Hulgaard T. and Vehlowy, 2013)

- Issue of meeting air quality required.
- Ability of classifying ash as a poisonous particle.
- Disposal of by-products of the process.
- Issues relating to the conflict land use acts.
- Biological resources disturbances.

- Making use of large amounts of water for cooling purposes.
- Changes to seeing quality due to traffic pattern and powers.
- Transportation effect of loading from the source to the incinerator.
- Uncertainties and opposition by the people because of safety, health, traffic, odour. That is why it is necessary and more economical for the plant to be located close to urban centres where the municipal solid waste is generated.
- Possible conflicts of which of the process the municipal solid waste be used, is it for electricity generation, waste reduction technique or is it recycling?

**Types of Incinerators**

**Modular incinerators**

These equipment units are mostly fabricated component with small capacities ranging from 6 to 122 tons of MSW per day usage (White, et. al, 1999). Most of these facilities consist of two and five chambers summing to between 20 to 420 tons daily carriage (White, et.al, 1999). The outcome of most of these facilities is steam which can be used to produce electricity. Most of these facilities are used for smaller settlement as they are not big enough to produce much energy. It is easier to design and fabricated as such has some economic advantage. "Generally, capital costs per ton of capacity are much lower for modular incinerator than for other municipal solid waste incineration options" ((Hulgaard T. and Vehlowy, 2013).

Two combustion chambers are involved in modular incinerators as compared to the mass burn incinerators (Fellner, et. al, 2007). Gases that is generated in the first chamber which is the primary chamber flow to the second chamber which is the afterburner, to ensure that more complete combustion takes place. Also having the advantage of primary pollution inhibition process. "In addition, smaller-scale plants which is less than 60 tons per day mostly operate using a batch process, rather than continuously, operating only about 7 to 18 hours per day. This facility is simple and helps in minimizing pollution" (Otte, P.1995).

**Fluidized-bed incinerators**

This incineration system of municipal solid waste are mostly available in the western countries and the Asia, example in Japan, where there are currently more than 180 of such facilities in use (Chandler, et. al, 1997). This plant are of average sizes making use of MSW daily. “Fluidized-bed incineration is also capturing an increasing portion of the European municipal solid waste incineration market, though it is obvious that mass-burn facility is still dominating in the market. In summary, there is no much experience with fluidized-bed incineration process as compared to the mass burn facilities” (Albert, 1972).

“In a fluidized-bed incinerator, the stoker grate is replaced by sand and bed of limestone which help the incinerator to withstand high temperatures, input by an air distribution system. The heating of the bed and the increasing of the air velocities cause the bed to bubble, which gives rise to the term Òfluidized” (Albert, 1972). The differences are seen in the relationship between bed material and the air flow. It has lots of meaning for the kind of MSW that can be incinerated. Also, the quantity of energy transferred to the recovery plant.
These are related to source separation of component like glasses, metal objects and inert matters which does not do well in the incineration processes (Bain, et.al, 1996). Also, fluidized-bed systems is highly integrated. “It can successfully burn wastes of high varying moisture and heat content, which make inclusion of wood and paper, which are all recyclable and burnable,  not to be a major factor in their operation. These factors make it obvious that fluidized-bed technologies are more compatible with high-recovery recycling systems, since there might be less competition for waste streams that are both burnable and recyclable. This also makes fluidized-bed technology to be considered a very popular technology choice of municipal solid waste high-recycling cities in most of the developing world when they first had the thought of incineration” (Hulgaard T. and Vehlowy, 2013).

Cost comparative of fluidized bed incineration process and mass burn facility have not been fully concluded due to some environmental and other factor. Lots of researches are ongoing in the western world for the installations of these plant which is giving more ideas to Japan on the installation of these incineration component for the incineration of municipal solid waste for commercial purposes (Mashavu, et.al, 2001).

**Grate Incineration Technology**

These are used extensively for the burning of mixed MSW (Sreekrishman, et. al. 2004). In western countries approximately 85 % of installations treating municipal solid waste use grate incineration technology. This type of facility is used for heterogeneous MSW that contains less calorific quantity (Sreekrishman, et. al. 2004). “The grate systems incineration technology include:

- Reciprocating grates
- Roller grates
- Reversed feed grates

Grate incinerators also have the following components:

- Municipal solid waste feeder
- incineration grate
- bottom discharger for ash
- incineration air duct system
- incineration combustion chamber
- Secondary and auxiliary burners

The operation involves the residence time of the waste into the incineration grates and does not exceed one hour” (Fellner, et.al, 2007). “The primary air supply ensures the direct combustion of the waste, while the secondary air seeks to achieve turbulent mixing of the waste for the complete combustion to take place. In order to accomplish complete combustion of the gases it is necessary for the gases to be at a very high temperature for some seconds. The completion of the gases coming out is shown by the levels of the carbon monoxide in the off gases. Auxiliary firing systems help in keeping the combustion gases at the reasonable temperature levels” (Otte, 1995). “The grates need to be cooled because the air is added from the bottom and high temperatures can damage the grate. There are two types of grate cooling systems and these include the water cooled grate and the air cooled grate. The utilization of the generated heat from the process of grate incineration process, since the combustion is exothermic is most commonly made through the generation of high-pressure and superheated steam coming out from the heat exchange between the flue gas which has help in absorbing the most of the heat produced and the water, in a boiler.

There are two options for the utilization of the superheated steam.

- Mainly to produce electricity alone: In This process, the high pressure steam is driven to a turbine and generator set. The energy content of the steam is now converted to kinetic energy, which is then converted to electricity through the generator and the excess heat of the low-pressure steam is cooled” (Rechberger).

- “Process to produce both electricity and hot water, also referred to as Combined Heat and Power process: In this process, the high pressure steam is driven to a turbine and generator set and the energy content of the steam is converted to kinetic energy, which is then converted to electricity through the generator. The excess heat of the low-pressure steam is converted to hot water, in a condenser, and can be used for district heating” (Rechberger, 2011).

### 2.4.2 ANAEROBIC DIGESTION POWER PLANT

Anaerobic digestion can be described as the way of decomposition of MSW without the application of oxygen to obtain methane. This product could be received and used as fuel to generate electricity energy (Demirel and Scherer, 2008). Biogas which is also known as biofuel means a gas produced by the biological disintegration materials without application of oxygen (Chen, et al, 2014). Biogas comes from biogenic matter and is a typical example of biofuel (Hutman et al, 2000). A particular type of fuel is particularly obtained in this process of anaerobic digestion of biodegradable matter which include municipal solid waste, biomass, sewage, manure, energy crops, energy crops (Renewable Waste Intelligence, 2013). This type of biofuel contains mainly of carbon dioxide and methane (Demirel and Scherer, 2008). This depend greatly where it is coming from, that where it is being produced. Biofuel can also be called marsh, swamp, and digester gas or simply as landfill gas (Ratanatamskul, et al, 2015). Anaerobic digester is a typical name given to a biofuel or biogas plant that make use of agricultural waste and other crops for energy production (Ratanatamskul, et al, 2015).
Biofuel could be produced efficiently with the utilization of anaerobic digester (Ratanatamskul, et al, 2015). The major raw materials to be fed into this type of plant are energy crops which include maize silage or biodegradable wastes materials, food waste and sewage sludge (Bouallagui, et al, 2003).

“This material helps in preventing oxygen from accessing the waste and anaerobic bacterials activities” (Poizot and Dolhem, 2011). “This gas builds up and gradually given up into the atmosphere if the landfill site has not been properly designed to capture the gas” (Beigi, et al, 2009). “Landfill gas is hazardous for some reasons, which include Landfill gas becoming explosive when it is coming out from the landfill and gets contact with oxygen” (Chen, et al, 2008). The lower explosive limit for methane is between 6% and 17% (Demirel and Scherer, 2008). The methane content in the biogas is more than 23 times efficient as a greenhouse gas than carbon (IV) oxide (Demirel and Scherer, 2008). It is a confirmed situation that uncontained landfill gas that is released into the atmosphere contributes significantly to the global warming effects (Poizot and Dolhem, 2011). It is obvious that landfill gas contribute to the formation of photochemical smog (Alkaya and Demirer, 20011).

**Design Factors**

The process of anaerobic digestion is efficiently control by the following processes (Hajji, et al, 2016):

(i) The type of waste to be digested.

(ii) Waste concentration.

(iii) Waste temperature.

(iv) The toxic materials present in the waste particle.

(v) The alkalinity and the PH of the waste materials.

(vi) The hydraulic retention time.

(vii) The solids retention time.

(viii) The ratio of food to microorganisms.

(ix) The digester loading rate.

(x) The rate at which toxic end products of digestion is evacuated.

**Waste Characteristics**

It should be noted that not all waste constituents are degraded at the same rate or completely digested to produce gas through the process of anaerobic digestion (Takashimia and Speece, 1989). There are some anaerobic bacteria that does not degrade some hydrocarbons during the process of anaerobic digestion (Strik, et al, 2005). Wastes that are not quickly dissolve in water takes a lot of time to breakdown, and as such breakdown slowly with time (Izumi, et al, 2010).

**Temperature**

The anaerobic bacteria consortia function under three temperature ranges. Psychrophilic temperatures of less than 68 degrees Fahrenheit produce the least amount of bacterial action. Mesophilic digestion occurs between 68 degrees and 105 degrees Fahrenheit. Thermophilic digestion occurs between 110 degrees Fahrenheit and 160 degrees Fahrenheit" (Hajji, et al, 2016). "The optimum mesophilic temperature is between 95 and 98 degrees Fahrenheit. The optimum thermophilic temperature is between 140 and 145 degrees Fahrenheit. The rate of bacterial growth and waste degradation is faster under thermophilic conditions" (Bouallagui, et al, 2003). On the other hand, thermophilic digestion produces an odorous effluent when compared to mesophilic digestion. Thermophilic digestion substantially increases the heat energy required for the process (Suhartini, et al, 2014). "In some cases, sufficient heat is not available to operate in the thermophilic range. This is especially true if flush systems areused or the milk parlour waste is mixed with the scraped manur(Bouallagui, et al, 2003). "Large quantities of dilution flush water must be heated to the digester's operating temperature" (Izumi, et al, 2010). "During cold weather, control of the flush volume is critical in maintaining adequate digester temperatures. Seasonal and diurnal temperature fluctuations significantly affect anaerobic digestion and the quantities of gas that is coming out. Operational control and bacterial storage has to be taken into consideration in the process of designing to maintain process stability and strength under a variety of temperature conditions. Temperature is a universal process variable as it influences the rate of bacterial activities and the amount of moisture in the biogas" (Hajji, et al, 2016).

**Ph**

In most cases, bacteria that produce methane normally need a neutral to a little bit of alkalinity of pH6.8 to 8.7 in order to produce the substance (Yang, et al, 2015). Most bacteria that aid in the formation of acid grows fasterthan that which aid in the formation of methane (Demirel and Scherer, 2008). If that which produce acid is growing faster than that which produce acid, it is well known that it would produce more acid in which the methane is likely not to consume or absorb all (Demirel and Scherer, 2008). In this situation, more acid will be available and may build up in the set-up (Beigi, et al, 2009). If large quantity of methane bacterial is produced in the anaerobic digester plant, it would therefore affect the stability of the pH (Yang, et al 2015).

**Hydraulic Retention Time (HRT)**

In anaerobic digestion plant design, the process is designed to make sure that the waste materials are kept for some reasonable number of days before being used for the processing (Yang, et al, 2015). This number of days that the waste particles are kept before being used is known as hydraulic retention time (Takashimia and Speece, 1989). The Hydraulic Retention Time is mathematically expressed as the size of the reservoir or tank over the material daily intake (Ratanatamskul, et al, 2015). The hydraulic retention time is a very important aspect in the anaerobic digestion plant as it helps to know the number of days or time the bacterial would grow and the subsequent conversion of the organic matter to biogas (Sreekrishman, et al, 2004). Converting volatile solids to gas are highly enhance by hydraulic retention time and the volatile solid materials (Sreekrishman, et al, 2004).

**Solids Retention Time**

Solid retention time has remarkably helped in the conversion of solid materials or municipal solid waste in the reservoir to gas (Sreekrishman, et al, 2004). It helps greatly in stabilizing the digester plant. It is simplified as solids maintained in the digester divided by solid waste engage per day (Sreekrishman, et al, 2004).

**Digester Loading**

Both retention times does not give the full details of waste material. That is the concentration in the anaerobic digestion plant (Takashimia and Speece, 1989). In the biogas plant, not all the waste are equal, some are somehow diluted while others are concentrated (Suhartini, et al, 2014). The waste particles that are high in concentration tend to produce more gas that those that are diluted (Yang, et al, 2015). Digester loading is predominantly used in measuring the performance of anaerobic digester size and its performance (Hutman, et al, 200). The loading can be measured in weight of MSW per cubic metres of the digester size (Ratanatamskul, et al, 2015). It is mathematically expressed in unit form as ($kg / m^3 / d$) (Sreekrishman, et al, 2004). When calculating digester loading, it has to be taken into account, the hydraulic retention time (Takashimia and Speece, 1989 ).

**Food to Micro-Organism Ratio**

Another major factor in controlling the processes in the anaerobic digestion plant is the food to micro-organism ratio (Chen, et al, 2015). At a particular temperature, it is a very little food per day that the bacterial consume in a particular time (Strik, et al, 2005). It is proper to supply a particular number of bacteria each time or simply per day to equally consume a particular quantity of municipal solid waste (Strik, et al, 2005). Therefore, the food to micro-organism is the ratio of thequantity of MSW to the quantity of bacteria present to decompose theMSW (Yang, et al, 20015). For the waste to be converted to biogas optimally, a lower food to microorganism is required (Strik, et al, 2005). The efficiency of the anaerobic digester loading can be enhance by bringing down the food to micro-organism ration and thereby raising the concentration of the municipal solid waste in the digester (Sreekrishman, et al, 2004). Furthermore, decreasing the digester loading, improves the efficiency of the MSW in the plant (Strik, et al, 2005).

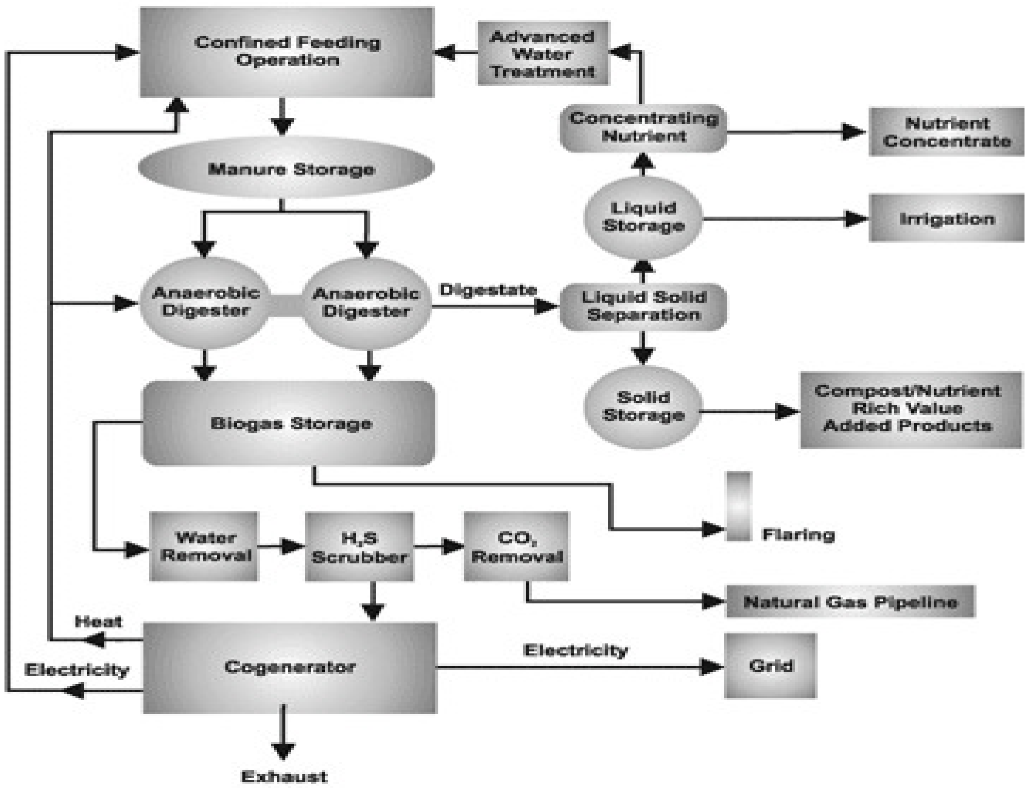


Plate 2.1: Flow chart of energy from waste for Anaerobic Digestion (Ratanatamskul, et al, 2015)

### 2.4.3 GASIFICATION

Gasification is a process that converts organic or fossil based carbonaceous materials into carbon monoxide, hydrogen and carbon dioxide. This is done by reacting the material at high temperatures without combustion, with a controlled quantity of oxygen and steam. This resulting in the production of syngas or producer gas which is a fuel. The power derived from the combustion and gasification of gasified compound is a source of renewable energy if the compounds used was biomass.

The important of gasification is that using the syngas is more efficient than direct combustion of the original fuel because of its combustion at higher temperatures, so that the thermodynamic upper limit to the efficiency is higher or not applicable" (Feldmann, 1973). "Another important of Gasification is that materials that would have disposed of as biodegradable waste are equally used for gasification process. The high-temperature process gives out corrosive ash elements such as chloride and potassium, allowing clean gas production from problematic fuels.

Gasification of fossil fuels is currently widely used on industrial scales to generate electricity" (Morris, 1998).

"The process of producing energy using the gasification method has been in use for more than 180 years. During that time coal and peat were used to power these plants (Smoot and Smith, 1985). Initially developed to produce town gas for lighting & cooking in 1800s, this was replaced by electricity and natural gas, it was also used in blast furnaces but the bigger role was played in the production of synthetic chemicals where it has been in use since the 1920s" (Smoot and Smith, 1985).

"It was obvious that before the world war that there was need for gasification as there were no enough fuel to meet the need of the people and satisfy the usage. Wood gas generators, called were used to power motor vehicles the developed countries. In the early and mid-1940's, trucks, earth movers and some agricultural equipment were energized by gasification. It was obvious that there were a high number of vehicles and other earth movers were running on producer gas" (Reed and Gaur, 1998).

**Chemical Reactions**

1. The dehydration or drying process occurs at around 100°C. Typically the resulting steam is mixed into the gas flow and may be involved with subsequent chemical reactions, notably the water-gas reaction if the temperature is sufficiently high enough (Evans and Milne 1997).
2. The combustion process occurs as the volatile products and some of the char reacts with oxygen to primarily form carbon dioxide and small amounts of carbon monoxide, which provides heat for the subsequent gasification reactions**.** The letter C represent a carbon-containing organic compound, the basic reaction is hereby represented (Hollenbacher, 1992).
3. "The gasification process occurs as the char reacts with carbon and steam to produce carbon monoxide and hydrogen". $C + H_2O \rightarrow H_2 + CO$ (Evans and Milne, 1997).
4. "In addition, the reversible gas phase water-gas shift reaction reaches equilibrium very fast at the temperatures in a gasifier". The equation is shown below; $CO + H_2O \leftrightarrow CO_2 + H_2$( Evans and Milne, 1997).

It invariably means that some amount of energy is used in the reaction to enable organic matters to be combusted to produce energy and carbon dioxide, which give room to the second reaction to further convert other organic matter to additional carbon dioxide and hydrogen. More reactions takes place when the carbon (II) oxide formed and residual moisture from the biodegradable matter produce excess carbon dioxide and methane.

**Gasification Processes**

There are many types of gasifiers currently in use for many engineering purposes, namely:" counter-current fixed bed, co-current fixed bed, fluidized bed, entrained flow, plasma, and free radical (NNFCC Project, 2009, PIER, 2015).

**Challenges of Gasification Technology**

Pre-processing of the municipal solid waste affect significantly the power output from the biogas. The consumption of high quantity of oxygen. This act as a gasification agent is also a big challenge in the gasification process (Morris, 1998). Obtaining long service intervals in the plant is considered as a serious challenge (Fryda, et al, 2008).

**Current Applications**

Syngas is widely used for production of heat and for mechanical and electrical generation of power. Producer gas gives greater control over power levels when compared to solid fuels, leading to more efficient and cleaner operation (Boerrigter, et al, 2005). It ca also be used for making other energy substances (Boerrigter, et al, 2005). Gasifiers plant offer an adjustable option for thermal technology applications, as they can be converted into existing gas fueled devices such as ovens, furnaces, boilers, etc. (Boerrigter, et al, 2005). Large-scale gasification technology is currently mostly used to produce electricity from fossil fuels such as coal, where the biogas is combusted in a gas turbine (Deurwaarter, et al 2005). Gasification is also used industrially in the production of electricity, ammonia and liquid fuels using Integrated Gasification Combined Cycles with the possibility of producing methane and hydrogen for fuel cells. IGCC is also a more efficient method of $CO_2$ capture as compared to conventional technologies" (Dry, 1981).

### 2.4.4 PYROLYSIS

This can be defined as the thermochemical breakdown of matter at a very high temperatures without the application of oxygen or any other element (Karagoz, 2009). "It is gotten from the Greek word pyro meaning fir and lysis meaning separating" (Karagoz, 2009).

Pyrolysis is a thermolysis process, which is as a result of organic matter being exposed at a very high temperature (Zabaniotu and Karabelas, 1999). Charring is one of the products of pyrolysis. This required the wood to be burnt to a temperature of over 1600°C (Ryu, et al, 2007). Pyrolysis also takes place when trees and grasses come in contact with volcanic eruptions, a sort of mild earth movement and when solid fuels are burning (Zabaniotu and Karabelas, 1999). Excess of pyrolysis, result in a process term carbonization (Mohan, et al, 2007).

These special and identical ways in which pyrolysis are applied could be given different names such as, cracking, destructive distillation and dry distillation (Aho, et al, 2008).

Pyrolysis can be used in analysing elements and compounds. It can also be used for spectrometry. It found its most usefulness in carbon dating. Many important chemical element, for example sulfuric acid and phosphorus, were discovered through this process. It is also the basis of pyrography (Demirbas, 2005). It happened that the ancient men made a combination of element like methanol and other hydrocarbons from the process of pyrolysis of wood (Bridgwater, 2004).

It is practically impossible, to get a totally oxygen-free environment. This is because some oxygen is available in the pyrolysis process. A little quantity undergo oxidation process (Demiral and sensoz, 2008). The pyrolysis process is applicable to breakdown organic matter. This is done in the availability of superheated steam or water. It is also used in the cracking of oil using steam (Zanzi, et al, 2001).

**Occurrence and Uses**

This process is regarded as the major chemical activity that takes place during the heating of wood. Carbohydrates and proteins undergo pyrolysis during cooking (Tsai, et al, 2007). Pyrolysis of fats needs a very high temperature and as such is preventable in cooking as it produces toxic and some flammable substance (Mante, 2008).

Cooking always takes place with the support of oxygen, other condition of temperatures and environmental issues applied (Demiralsensoz, 2008). “In particular, the pyrolysis of proteins and carbohydrates begins at temperatures much lower than the ignition temperature of the solid residue, and the volatile sub products are too diluted in air to ignite” (Hill, 2007).

Pyrolysis of carbohydrates and proteins need a very high temperature, so it does not occur where total boiling of the product does not take place (Hills, 2007). This process is very useful in the production of peanuts. It is also useful in the production of almonds and also found its usefulness in the production of coffee (Lua, et al, 2004). The system of pyrolysis is not only stop at the outer layer as these process involve dry

materials (Aho, et al, 2008). In every of these processes, pyrolysis developed many of these materials that help in the biological characteristics, flavour, colour of the product (Mohan, et al, 2007). Remarkably, those unpleasant substance that may spoil the taste of substance are destroyed in the process of pyrolysis (Mohan, et al, 2007).
Conditioned pyrolysis of sugars at a very high temperature produces beige and caramel which is used as a colouring agent for industries and other related factories (Hills, 2007).
It is obvious that from the ancient days, Pyrolysis is known as the process of turning wood into charcoal for industrial scale. Sawdust could be applied for this process (Aho, et al, 2008).

The complete burning of wood produces the process of carbonization which is a complete process of pyrolysis which leave inorganic ash and carbon as residues (Toole, et, al, 1961). The heat produced by heating some of these wood and the by-products pyrolyzes the pile completely (Toole, et al, 1961). The best option of volatile product condensation and less pollution experience in the process is to burn the wood in a close system or container (Papadikis, et al, 2011). Remains of partial organic pyrolysis for instance from burning fires, are proved to be the most important aparatus in the type of soils available around some basins which is highly required for agricultural purpose in those regions. There are presently lot of efforts and interest in creating these type of soil in other part of the world for agricultural purposes by the process of pyrolysis of organic matters and biochar (PYTEC 2005).
It is obvious and proven in the process of pyrolysis that biochar improves the soil ecology and texture. By so doing optimizes the ability of the soil to hold fertilizers and gradually releases them (PYTEC, 2005). This process, as it produces the nutrients at much lower value, it helps remarkably in minimizing the risk of water table contamination (PYTEC, 2005).

Pyrolysis is used extensively in converting coal into coke for metallurgical processes, especially in the production of iron and steel. It is also known that Coke can also be gotten from the petroleum refining processes (Mohammed, et al, 2012).
The coke process involves burning the material in tight system to a high temperature of about 3,300 °C. This help the molecules to be decomposed into smaller volatile substances. Which allow the system, and the porous residue that contain carbon and

non-biodegradable ash (Zhao, et al, 2001). Carbon fibers are widely used in the production of yarns and other textile materials (Hill, 2007).

Another means of application of this process is of coating. In this case, a preformed mixture with a coating of carbon element is applied.(Ryu, et al, 2007). “This is typically applicable in a fluidized bed reactor heated to a very high temperature” (Aho, et al, 2008). “As a means of producing bio-oil which can be used as a biofuel, with the removal of valuable bio-chemicals which is used as food additives or pharmaceuticals, pyrolysis processes produce lot of chain outcome from these processes” (Zhang, et al, 2007).

Higher efficiency is obtained in the pyrolysis process in which finely grounded feedstock is heated to a very high temperature in a very short interval of time (Brown, et al, 2001).

Biofuel is also obtained by pyrolysis from other types of feedstock. Including waste from turkey and pig husbandry. This is a process termed thermal depolymerization in addition to other processes aside pyrolysis (Tsai, et al, 2007).

Anhydrous pyrolysis is another method of application of pyrolysis to produce biofuel from plastic waste. This gave room to the plan of moving some vehicles, other earth movers and airplanes using fuel from the recycled plastic waste (Scott, et al, 1999).

“Pyrolysis of waste tires can separate solids in the tire, such as steel and black carbon, from volatile liquid and other gaseous compounds that can be used as biofuel” (Scott, et al, 1999). Pyrolysis of waste from tires and other plastics has been mostly obtained in the whole world. There are marketing, economic and legislative bottleneck for efficient adoption of this process (Toole, et al, 1961).

**Processes**

- Incomplete burning of the wood products by injecting air results to bad outcome of products (Mohan, et al, 2007).
- “Direct heat transfer with a high temperature gas, the most current one being product gas that is continuously heated and recycled but the problem of providing high quantity of heat with reasonable gas flow rate” .

- Direct heat transfer with circulating solids in which Solids transfer heat between a burner and a pyrolysis reactor which is tough and effective but a very complex technology" .(Brown, et al, 2001).

**Industrial Sources**

There are many sources of organic materials which could be used as feedstock for pyrolysis (Ahmad, et al, 2010). Distillers grain and paper sludge are some industrial by-products of pyrolysis (Ryu, et al, 2007). Mechanical, biological treatment and anaerobic digestion are some of the possible integration of this process (Downie, 2007).

**Industrial Products**

- There are lots of energy needed for other production processes and pyrolysis which make use of biogas. For example, a combination of hydrogen and carbon (II) oxide which is produced in enough quantity (Yeboah, et al, 2003).
- Fertilizer in a biochar form can also be gotten from solid char which could be recycled or burned as energy (Asadullah, et al, 2007).

**Table 2.1 POWER GENERATION STATISTICS 2010 - 2014**

(Energy Produced, Turnover and Cost of Operation)Source: National Bureau of Statistics & Nigerian Electricity Regulatory Commissionaa

NIGERIAN ELECTRICITY SUPPLY CORPORATION (NIGERIA) LIMITED

| YEAR (QUARTER) | TOTAL ENEGRY GENERAATED (MWH) | TURNOVER(=N=) | COST OF OPERATION LESS LABOUR COST (=N=) |
|---|---:|---:|---:|
| 2010-1 | 5,717,100.00 | 102,928,435.00 | 56,503,619.00 |
| 2010-2 | 5,828,129.00 | 91,486,241.00 | 68,925,194.00 |
| 2010-3 | 9,579,453.00 | 131,767,707.00 | 67,726,536.00 |
| 2010-4 | 9.310.433.00 | 157.759.670.00 | 77.705.796.00 |
| 2011-1 | 7,106,293.00 | 113,751,572.00 | 70,252,826.00 |
| 2011-2 | 6,492,563.00 | 120,525,811.00 | 77,610,969.00 |
| 2011-3 | 7,299,087.00 | 134,314,066.00 | 81,010,499.00 |
| 2011-4 | 5,701,610.00 | 103,429,588.00 | 78,048,589.00 |
| 2012-1 | 6,034,610.00 | 118,869,427.00 | 80,939,440.00 |
| 2012-2 | 6.378.710.00 | 153.190.573.00 | 101,333,028.00 |
| 2012-3 | 6,473,896.00 | 181,924,904.00 | 69,902,086.00 |
| 2012-4 | 7,375,650.00 | 187,644,535.00 | 74,660.238.00 |
| 2013-1 | 7,004,010.00 | 173,950,373.00 | 76,581,331.00 |
| 2013-2 | 6,658,166.00 | 183,480,808.00 | 77,579.273.00 |
| 2013-3 | 8,281,938.00 | 206.162,242.00 | 81.496.250.00 |
| 2013-4 | 7.413.946.00 | 189.343.023.00 | 94.310.622.00 |
| 2014-1 | 7,598,306.00 | 192,836,345.00 | 95,167,201.00 |
| 2014-2 | 8,086,013.00 | 202,674,802.00 | 101,333,026.00 |
| 2014-3 | 7,427,726.00 | 212,061,004.00 | 91,613,671.00 |
| 2014-4 | 8,012,866.00 | 202,687,647.00 | 84,518.937.00 |
| **TOTAL** | **143,780,505.00** | **3,160,788,773.00** | **1,607,219,131.00** |

**Table 2.1 POWER GENERATION STATISTICS 2010 – 2014 CONTINUED**

| | TOTAL ENEGRY GENERAATED (MWH) | TURNOVER(=N=) | COST OF OPERATION LESS LABOUR COST (=N=) |
|---|---|---|---|
| 2010-1 | | | |
| 2010-2 | | | |
| 2010-3 | | | |
| 2010-4 | | | |
| 2011-1 | | | |
| 2011-2 | | | |
| 2011-3 | | | |
| 2011-4 | | | |
| 2012-1 | | | |
| 2012-2 | | | 891,562,640.00 |
| 2012-3 | 1,273.43 | 11.645.517.35 | 913,122,640.00 |
| 2012-4 | | | 891,562,640.00 |
| 2013-1 | | | 685,666,489.75 |
| 2013-2 | | | 690,667,691.10 |
| 2013-3 | | | 790,090,486.99 |
| 2013-4 | 17,442.02 | 158,235,404.87 | 807,875,511.92 |
| 2014-1 | | | 754,244,684.24 |
| 2014-2 | 13,109.65 | 120,588,143.62 | 747,321,619.24 |
| 2014-3 | | | 747.025.979.24 |
| 2014-4 | 784.02 | 7.125.971.69 | 791,054,862.97 |
| **TOTAL** | **32,609.12** | **297,595,037.53** | **8,710,195,245.45** |

NOTE: COMMERCIAL OPERATION COMMENCED IN APRIL, 2015
BUT TRAIL RUNS OF SOME UNITS TOOK PLACE IN 2013 AND 2014
COST OF OPERATIONS EXCLUDES:HEAD OFFICE EXPENSES, PROVISION OF DOUTHFUL DEBT

**Table 2.1 POWER GENERATION STATISTICS 2010 – 2014 CONTINUED**

| | TOTAL ENERGY GENERATED (MWH) | TURNOVER(N) | COST OF OPERATION LESS LABOUR COST |
|---|---|---|---|
| 2010-1 | | | |
| 2010-2 | | | |
| 2010-3 | | | |
| 2010-4 | | | |
| 2011-1 | | | |
| 2011-2 | | | |
| 2011-3 | | | |
| 2011-4 | | | |
| 2012-1 | | | |
| 2012-2 | | | |
| 2012-3 | | | |
| **2012-4** | | | |
| 2013-1 | | | 10,184,862.92 |
| 2013-2 | 77,734.28 | 703,852,515.68 | 587,469,646.47 |
| 2013-3 | 165,633.72 | 1,503,874,186.14 | 915,970,437.74 |
| 2013-4 | 201,120.17 | 1,823,397,029.25 | 1,184,989,989.83 |
| 2014-1 | 326,384.06 | 2,970,665,182.53 | 1,324,249,096.66 |
| 2014-2 | 328,917.49 | 2,991,776,850.60 | 1,289,356,953.76 |
| 2014-3 | 382,741.60 | 3,526,763,990.15 | 1,446,933,431.92 |
| 2014-4 | 500,613.88 | 4,700,096,722.30 | 2,126,137,092.49 |
| **TOTAL** | **1,983,145.20** | **18,220,426,476.65** | **8,885,291,511.79** |

NOTE: COMMERCIAL OPERATION COMMENCED IN MAY 2013
— BUT TRAIL RUNS OF SOME UNITS TOOK PLACE IN APRIL 2013
COST OF OPERATIONS EXCLUDES: HEAD OFFICE EXPENSES, PROVISION OF DOUBTFUL DEBT

## 2.5 INTEGER LINEAR PROGRAMMING (ILP)

According to Brucker and Knust, 2000, an integer linear programming problem is a mathematical optimization or feasibility program in which some or all of the variables are restricted to be integers. In some settings, the term is called integer linear programming (ILP), in which case, the objective function and the constraints are linear. A very special case is given 0-1 integer linear programming, in which unknowns are binary, and only the restrictions must be satisfied (Brucker and Knust, 2000).

**Canonical and Standard Form for ILPs**

An expression for integer linear program in canonical form is as follows;

$$\begin{array}{ll} \text{maximize} & \mathbf{c}^\mathrm{T}\mathbf{x} \\ \text{subject to} & A\mathbf{x} \le \mathbf{b}, \\ & \mathbf{x} \ge \mathbf{0}, \\ \text{and} & \mathbf{x} \in \mathbb{Z}^n, \end{array}$$

The standard form for ILP is mathematically shown as follows;

$$\begin{array}{ll} \text{maximize} & \mathbf{c}^\mathrm{T}\mathbf{x} \\ \text{subject to} & A\mathbf{x} + \mathbf{s} = \mathbf{b}, \\ & \mathbf{s} \ge \mathbf{0}, \\ \text{and} & \mathbf{x} \in \mathbb{Z}^n, \end{array}$$

Where entries of $\mathbf{c}$, $\mathbf{b}$ are vectors and $A$ is a matrix, with integer values.

# CHAPTER THREE

# MATERIALS AND METHODOLOGY

This methodology involves sampling identification, sorting technique processes and laboratory work in order to estimate the calorific value of municipal solid waste (MSW) in Uyo metropolis. Of great important was the electricity generation method.

## 3.1 WASTE COLLECTION

Secondary information for collection and quantity of municipal solid waste in Uyo metropolis was source from AkwaIbom State Waste Management and Environmental Protection Agency.

## 3.2 MUNICIPAL SOLID WASTE SAMPLING

The spot sampling method was adopted in the sampling and sorting procedure. The spot sampling method required the sample to be taken from dumpsites from the same source where an amount of waste (100kg) is collected and the total quantity taken from 10 sites to form a sample value of 1000kg, to be sorted. 10 sample of MSW collected from waste from 10 identified site in Uyo. The process took place in November and December, 2014 happened to be dry season in the city. The sorting was carried out base on the following components; Organic, paper- carton, glass, plastics, iron and metal packaging, textiles, wood, leather and elastics, inert matters, others.

## 3.3 THE SEGREGATION PROCESS AND RATIO PREPARATION

The samples were segregated into their various components. Combustible municipal Solid waste mix (MSWM) of two combinations of six different mix (plastic/textile, wood,

leather-P/TWL, plastic organic-P/O, plastic/paper-carton-P/PC, textile, wood, leather/organic-TWL/O, textile, wood, leather/paper-carton-TWL/PC, organic/paper-carton-O/PC) across five different ratios of 9:1, 8:2, 7:3, 6:4, 5:5 were prepared taking into consideration, their availability (i.e. the total quantity of waste to be combusted at a particular time to have the required calorific value).Three combinations of four different mix (P/TWL/O, P/TWL/PC, P/O/PC and TWL/O/PC) across three different ratios of 5:4:1, 5:3:2 and 4:3:3 were also prepared(combusted in a bomb calorimeter). The selection ratio were based on the higher calorific value also considering availability combining with the one with next calorific value and also considering availability.

## 3.4 INTERPRETATION OF REPRESENTATION

Plastics – P

Textiles, wood and leather- TWL

Organic- O

Paper-carton- PC

Glass- G

Iron and metal packaging- IM

Inert matter- INM

Others-OT

Plastics/Textiles, wood, leather- P/TWL

Plastics/Organic- P/O

Plastics/Paper-carton-P/PC

Textiles, wood, leather/Organic- TWL/O

Textiles, wood, leather/Paper-carton- TWL/PC

Organic/Paper-carton- O/PC

Paper/Textiles, wood, leather/organic- P/TWL/O

Plastics, Textiles, wood, leather/paper-carton- P/TWL/PC

Plastics/organic/paper-carton- P/O/PC

Textiles, wood, leather/organic/paper-carton- TWL/O/P

## 3.5 LINEAR PROGRAMMING MODEL

### Model Formulation

### Indexes

Let $i$ = Number of two combination of municipal solid waste ($i = 1,2,\ldots m$)

$j$ = Number of three combination of municipal solid waste ($j = 1,2,\ldots n$)

$k$ = Number of municipal solid waste ($k = 1,2,\ldots l$ )

**Parameters of the Model**

Let $x_i$ = Tons of *i* type of two combination of municipal solid waste

$y_j$ = Tons of *j* type of three combination of municipal solid waste

$A_i$ = Calorific value per unit ton of *i* type of two combination of municipal solid waste

$B_j$ = Calorific value per unit ton of *j* type of three combination of MSW

$p_k$ = Tons of *k* type of MSW

$Q_k$ = Maximum availability (tons) per year of *k* type of municipal solid waste

$$\text{Max} \quad \sum_{i=1}^{m} A_i x_i + \sum_{j=1}^{n} B_j y_j$$

Subject to

$x_1 = 0.9p_1 + 0.1p_2$

$x_2 = 0.8p_1 + 0.2p_2$

$x_3 = 0.7p_1 + 0.3p_2$

$x_4 = 0.6p_1 + 0.4p_2$

$x_5 = 0.5p_1 + 0.5p_2$

$x_6 = 0.9p_1 + 0.1p_3$

$x_7 = 0.8p_1 + 0.2p_3$

$x_8 = 0.7p_1 + 0.3p_3$

$x_9 = 0.6p_1 + 0.4p_3$

$x_{10} = 0.5p_1 + 0.5p_3$

$x_{11} = 0.9p_1 + 0.1p_4$

$x_{12} = 0.8p_1 + 0.2p_4$

$x_{13} = 0.7p_1 + 0.3p_4$

$x_{14} = 0.6p_1 + 0.4p_4$

$x_{15} = 0.5p_1 + 0.5p_4$

$x_{16} = 0.9p_2 + 0.1p_3$

$x_{17} = 0.8p_2 + 0.2p_3$

$x_{18} = 0.7p_2 + 0.3p_3$

$x_{19}= 0.6p_2 + 0.4p_3$

$x_{20} = 0.5p_2 + 0.5p_3$

$x_{21} = 0.9p_2 + 0.1p_4$

$x_{22} = 0.8p_2 + 0.2p_4$

$x_{23} = 0.7p_2 + 0.3p_4$

$x_{24}= 0.6p_2 + 0.4p_4$

$x_{25} = 0.5p_2 + 0.5p_4$

$x_{26} = 0.9p_3 + 0.1p_4$

$x_{27} = 0.8p_3 + 0.2p_4$

$x_{28} = 0.7p_3 + 0.3p_4$

$x_{29}= 0.6p_3 + 0.4p_4$

$x_{30} = 0.5p_3 + 0.5p_4$

$y_1 = 0.5p_1 + 0.4p_2 + 0.1p_3$

$y_2 = 0.5p_1 + 0.3p_2 + 0.2p_3$

$y_3 = 0.4p_1 + 0.3p_2 + 0.3p_3$

$y_4 = 0.5p_1 + 0.4p_2 + 0.1p_4$

$y_5 = 0.5p_1 + 0.3p_2 + 0.2p_4$

$y_6 = 0.4p_1 + 0.3p_2 + 0.3p_4$

$y_7 = 0.5p_1 + 0.4p_3 + 0.1p_4$

$y_8 = 0.5p_1 + 0.3p_3 + 0.2p_4$

$y_9 = 0.4p_1 + 0.3p_3 + 0.3p_4$

$y_{10} = 0.5p_2 + 0.4p_3 + 0.1p_4$

$y_{11} = 0.5p_2 + 0.3p_3 + 0.2p_4$

$y_{12} = 0.4p_2 + 0.3p_3 + 0.3p_4$

$p_k \leq Q_k \, ; \qquad k = 1,2, \dots l$

$\sum_{i=1}^{m} x_i + \sum_{j=1}^{n} y_j = \sum_{k=1}^{l} Q_k$

$x_i \geq 0 \, ; \qquad i = 1,2, \dots m$

$y_j \geq 0 \, ; \qquad j = 1,2, \dots n$

## 3.6 TEST FOR CALORIC VALUE

Test procedure for calorific value (CV) of MSW by the Bomb Calorimeter was employed. The process involves the estimation of CV of analysed sample of MSW by the bomb calorimeter. The standard process does not take some safety procedure precautions into consideration in its usage. The laboratory technician, technologist or person making use can as his or her own, proffer the safety guide for its usage.(ASTM E711-87(2004).

## 3.7 EXPERIMENTAL SET-UP

**The drying process**

Sub- samples, each weighing 100kg were collected from the samples and drying in a cabinet (bomb calorimeter) at 90$^{o}$C to a particular weight for removal of water content to about 10% and calorific value were recorded.

**Determination of the optimal quantity of municipal solid waste mix**

Linear programming model was applied to obtain the best mix taking into consideration the availability, quantity and calorific value of municipal solid waste.

**Determination of the calorific value (CV) of municipal solid waste mix (MSWM)**

The CV for these components were carried out in accordance with **ASME E711-87** standard using the bomb calorimeter method.The major component in the experimental set-up involves the bomb calorimeter. This is the apparatus used in calculating the heat energy from the combustion process. The process of this equipment takes place in a water bath. The heat that is release into the water can be seen by the reading of the thermometer. The structure of the set-up involve the following:

- Steel bomb which contains stating materials
- Water bath for the bomb to be immersed
- Thermometer
- A motorized stirrer
- Ignition material

All the elements mentioned above are inside the external wall of the calorimeter. After the first temperature of the liquid is taken, the hot wire inside the bomb begins to react. The temperature is then taken after the combustion has taken place. The difference in temperature is then estimated.

The procedure is taking place in the atmospheric pressure which is below the oxygen in the atmosphere. This helps in the total combustion of MSW in the set-up. Data were taken for different types of MSW and MSWM in the calorimeter.

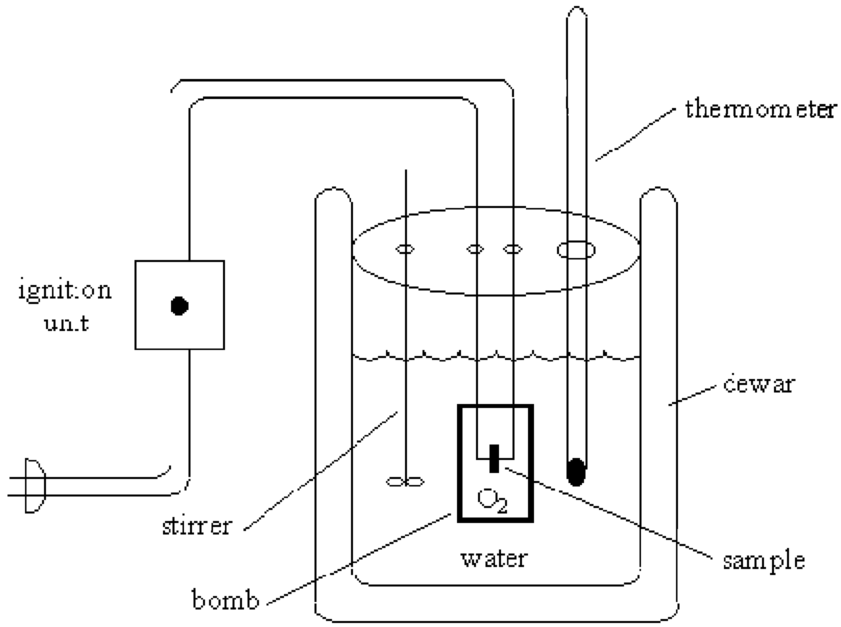


**Plate 3.1 The Bomb Calorimeter**

**Plate.3.2 pictorial view of the Bomb Calorimeter**

The set-up involves mainly of the following sample; Oxygen, stainless steel bomb, water. The dewar helps in maintaining heat present in the calorimeter not to be absorbed by the ambient.

*i.e.*, $q_{\text{calorimeter}} = 0$

$w_{\text{calorimeter}} = \; p \, \mathrm{d}V = 0$

Then, change in internal energy, $U$, for the set-up tending to zero

$U_{\text{calorimeter}} = q_{\text{calorimeter}} + w_{\text{calorimeter}} = 0$

The meaning of this process is that the set-up is isolated from other environment.

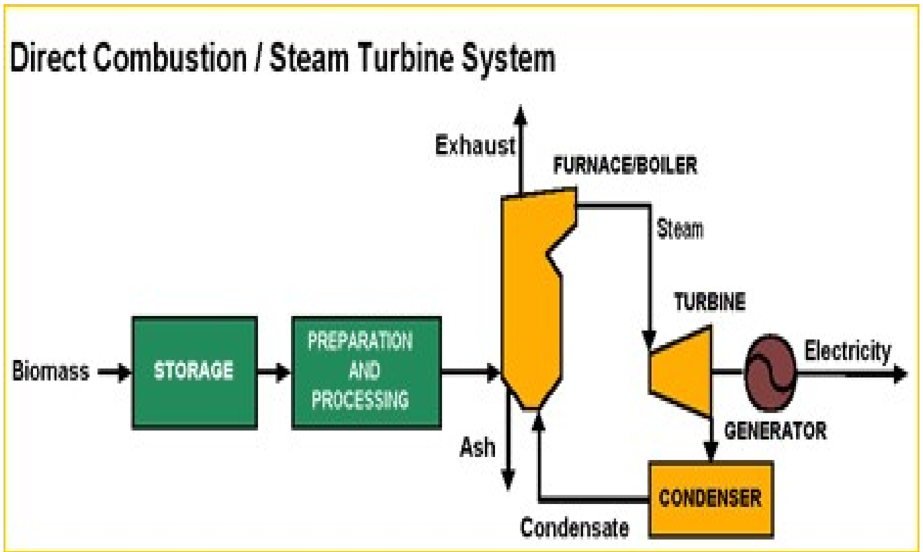


**Plate 3.3 Incineration/Steam Turbine System**

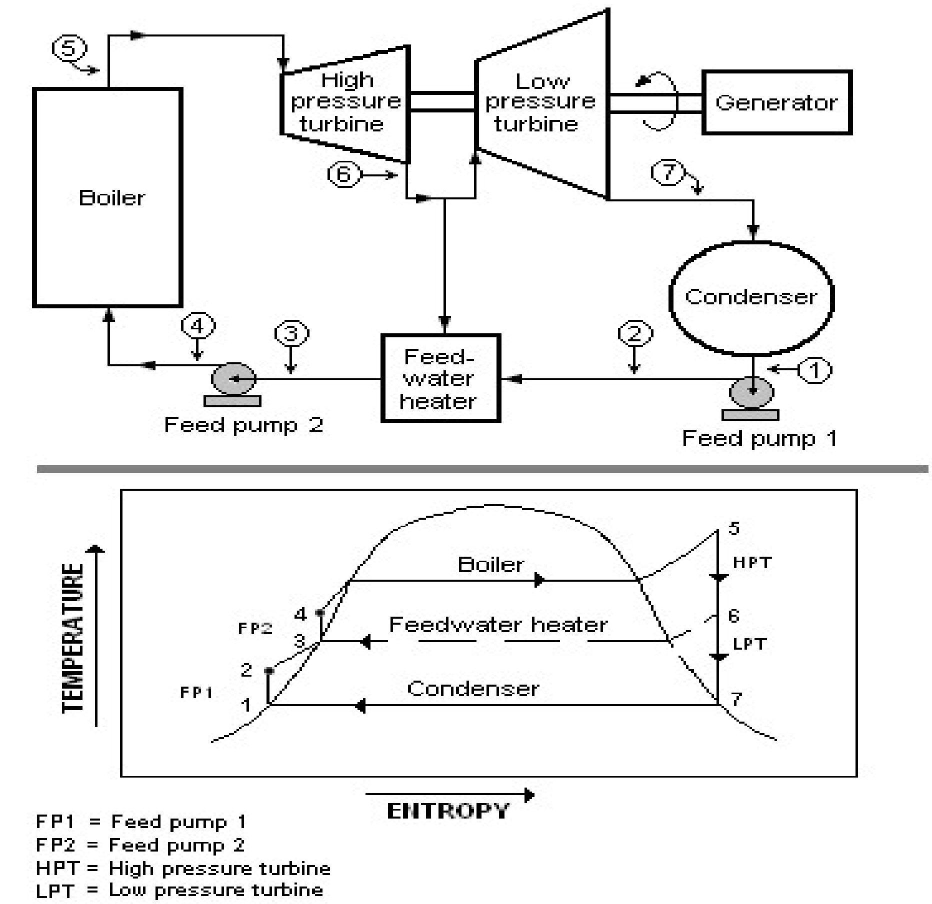


Fig 3.1 Thermodynamic process cycle

**THERMODYNAMIC EQUATION OF THE PLANT**

$Specific\ Volume,\ V_s = \frac{Volume}{mass} = \frac{V}{m}\ (M^3/Kg)$ ------------------------- **(1)**

$V_s = {}^1/_\rho$ $where\ \rho = mass\ density = {}^M/_V\ (Kg/m^3)$------------------------ **(2)**

$Specific\ volume, V_s\ is\ independent\ of\ both\ T\ and\ P\ (temperature\ and\ pressure) in\ simple$

$compressible\ systems\ \Rightarrow V = m * V_s$------------------------------------------------ **(3)**

$m = \rho * V$------------------------------------------------------------------------------ **(4)**

$$V_{saturated\ liquid} = V_f$$

$$V_{saturated\ vapour} = V_g$$

$m_{saturated\ liquid} = m_f$

$m_{saturated\ vapour} = m_g$

$for\ a\ liquid\ vapour\ mixture\ at\ equilibrium\ V = V_f + V_g\ (m^3) - - - - - (5)$

$m * V_s = V_f + m_g * V_f\ (m^3)$ -------------------------------------------------------------- (6)

$m = total\ mass\ in\ both\ phases\ (liquid\ and\ gaseous\ stage)$

$V = total\ volume\ occupied\ by\ both\ phases\ (liquid\ and\ gaseous\ stage)$

$m = m_f + m_g$-----------------------------------------------------(7)

***Rearranging (7) to eliminate $m_f$ from 6; $m_{f=} m - m_g$. Substituting for $m_f$ in (6) $\Rightarrow$***

*Rearranging (7) to eliminate $m_f$ from 6; $m_{f=} m - m_g$ . Substituting for $m_f$ in (6)$\Rightarrow$*

$m * V = (m - m_g) * V_g + m_g * V_f$----------------------------------------- *(8)*

*Now solving for* $V_{s=}V \Rightarrow V = V_f \left(\frac{m-m_g}{m}\right) + V_g \left(\frac{m_g}{m}\right), m^3/kg$------------ *(9)*

***Internal Energy***: *This is a thermodynamic property that is associated with change* in temperature ***U***⇒ $U = U_{liq} + U_{vap}$------------------------------------------------ *(10)*

**OR**

$m_{u=}m_{liq}u_f + m_{vap}$$__________________________________________$*(11)*

*Dividing by m and introducing the quality x gives*

*U*=$(1 - x)u_f + xu_g$---------------------------------------------------------------------- *(12)*

x⇒ quality in %

***Enthalpy***: *This can be expressed and calculated as*$H = mh$------------------- *(13)*

Where *H*=$Enthalpy$

$M = mass\ (kg)$

$h = Specific\ enthalpy\ (Kj/Kg$

***Specific enthalpy:*** *This is the property of the fluid*

$h = u + pv$-----------------------------------------------------------------------------------

*(14)*

*Where H=Internal energy (Kj/Kg)*

*P= absolute pressure* $(N/m^2)$

*V= specific volume* $(m^3/Kg)$

*Specific enthalpy of water*⇒$h_f = c_w(t_f - t_o)$-----------------------------------------*(15)*

*Where* $h_f = enthalpy\ of\ water$ *(kj/kg)*

$C_w = Specific\ heat\ of\ water = 4.19\ (kj/kg^oC$

$t_f = Saturated\ temperature\ (o_C)$

$t_o = refer\ temperature$

***Specific enthalpy of superheated steam*** *⇒*$h_s = h_g + C_{ps}(t_s - t_f)$--- *(16)*

*Where;*$h_s = enthalpy\ heat\ of\ steam\ at\ constant\ pressure = 1.860\ (kj/kgo_c)$

$t_f = Saturated\ temperature^o c$

$t_s = supersaturated\ steam\ temperature^o c$

$C_{ps} = 1.860\ (kj/kg^o c$ *at standard atmosphere and varies with temperature*

$C_{ps} = Specific\ heat\ of\ steam$

***Specific enthalpy of evaporation*** *⇒*$h_e = h_g - h_f$ ------------------------- *(17)*

*Where* $h_e = specific\ evaporation\ enthalpy$ *(Kj/kg) (parameters reference to the steam table).*

### 3.8 Related Dulong's Equations to Electrical Power Potential

Dulong equation is used extensively in the determination of the electricity potential of MSW in so many developed and developing countries. It can therefore, be applicable in the underdeveloped country, like Nigeria and Uyo as a case study.

The calorific value of municipal solid waste in Uyo metropolis is given by;

The summed product of the calorific value (MJ/Kg) of dry matter multiplied by the component of the municipal solid waste divided by the number of components that possess calorific value.

Therefore, Let **A**= Components in the MSW.

**B**= CV in (MJ/Kg) of dry matter

**C**= Components with calorific value=**5**

The summed product of the calorific value (MJ/Kg) of dry matter =

$\sum(A)X(B)/\mathrm{C}$

This value is multiplied by 1000 in order to have the MJ/Ton equivalent and then transformed to KWh/ton = MJ/ton.

Therefore, average CV of MSW generated in Uyo in KWh/ton = Average CV of MSW (MJ/ton)/3600 X 1000)

If we take the conventional thermal efficiency of 40%. The specific power output per ton of waste (Kwh/ton) occurs by multiplying the average calorific value by 0.40

The electrical potential for municipal solid waste mass combustion plant is estimated thus;

Electrical potential (MW) = (MSW generation X Specific energy release per tonne of MSW) / Average calorific value of waste)/ 1000

The value gives an indication of the maximum capacity level at which a municipal solid waste plant could be developed taking into consideration a 100% mass use of MSW produced in Uyo.

## 3.9 THE PRODUCTION ASSESSMENT

The electricity production assessment is aim at identifying some areas of research which include electricity output from the MSW in Uyo metropolis. The analysis of daily generation, monthly generation and yearly generation of MSW calculation using a particular range of load factor according to Panagiotis, 2003. Also, the total power production taking all factors of plant into consideration.

The concurrent evaluation of the heat flow rate (Btu/kWh) acts as a verification method to the calculations certifying their validity (Panagiotis, 2003).

**Load Factor**

The plant load factor can be explained as the ratio of Actual Operational Capacity over Optimal Operating Capacity (Panagiotis, 2003). In the particular MSW plant the Optimal Operating Capacity is 8MW and the Actual Operational Capacity is accounted in the range between 3.4 to 5.4 MW according to Ikywashima, a variation of load factor in the range of 34% to 54% is considered feasible taking some factors into For the combustion plant in research the current load factor is defined at 44% due to the plants' developed set-up complexity and capacity levels. Load Factor = Actual Operational Capacity/Optimal Operating Capacity.

**Heat Rate:**

In case of the current study, the heat rate for electricity production of one kilowatt-hour is given with a value of 3412 Btu/kWh which is equivalent to 3597.4kJ/Kwh (Panagiotis, 2003).

**Summary of the equations**

Quantity of MSW in combustor (Kg/hr) = (Btu/hr)/Average Btu/kg of MSW

Quantity of MSW in Combustor (Tonnes/day) = Qty of MSW (kg/hr) X 24/1000

Quantity of MSW in combustor (Tonnes/year) =MSW (Tonnes/day)X365

KWh Annual production=Maximum capacity X load factorX24X365

Heat rate= (Btu/hr) X 24 X 365/KWh Annual Production (Panagiotis, 2003).

## 3.10 STATISTICAL ANALYSIS FOR THE EXPERIMENTAL RESULTS

### Theoretical Background

### The Central Limit Theorem

If $x_1, x_2, x_3, \ldots\ldots x_n$ is a random sample of size n taken from a population (either finite of infinite) with mean $\mu$ and finite variance $\sigma^2$, and if $\bar{x}$ is the sample mean, the limiting form of the distribution of $\frac{\bar{x}-\mu}{\sigma/\sqrt{n}}$ as $n \to \infty$, is the standard normal distribution.

### Statistical Interval

When n is large, the quantity $\frac{\bar{x}-\mu}{s/\sqrt{n}}$ has an approximate standard normal distribution. Consequently $\bar{x} - Z_{\alpha/2}\frac{s}{\sqrt{n}} \le \mu \le \bar{x} + Z_{\alpha/2}\frac{s}{\sqrt{n}}$ ------------------------ (eqn 3.41)

is a large sample confidence interval for $\mu$ , with confidence level of approximately $100(1-\alpha)\%$ .

Equation (3.41) holds regardless of the shape of the population distribution. Generally, for central limit theorem n should be atleast 40 to use this result reliably, while for T-distribution, n should be atleast 5 to use the result reliably The central limit theorem generally holds for n ≥30.

**Data Description**

Sample Mean $\overline{\boldsymbol{x}} = \frac{x_1,\ x_2, x_3,\dots\dots x_n}{\boldsymbol{n}} = \frac{\sum_{i=1}^{n} x_i}{\boldsymbol{n}}$------------- (eqn.3.42)

Sample variance $\boldsymbol{S^2} = \frac{\sum_{i=1}^{n}(x_i - \overline{x})^2}{\boldsymbol{n-1}}$ --------------------------------------- (eqn.3.43)

Sample standard deviation $\boldsymbol{S} = \sqrt{\boldsymbol{s^2}}$--------------------------------------------(eqn 3.44)

## 3.11 ECONOMIC

In this type of a project to be developed in any metropolis or an urban centre, there is need for feasibility analysis to be taken into consideration. That is to say, is it going to be viable? Taking into consideration, the following;

- Net Present Value (NPV)
- Internal Rate of Return (IRR)
- Pay Back Period (PBP)

**Merits of Net Present Value (NPV)**

- The approach is consistent with the theory of wealth maximization.
- The approach considers the time value of cash.
- The approach considers the business flow of money in the period of the business.
- It helps in deciding whether to go into the business or not

**Summary of Net Present Value and Internal Rate of Return Comparison**

- NPV is more popular than the IRR.
- Where cash flow patterns are non-conventional, there may be nil or several internal rates of return making the internal rate of return impossible to apply.
- Net present value is powerful for selecting project according to their values.
- IRR are used where NPV cash flow are not directional.

## 3.12 MATERIALS AND CONSTRUCTION ANALYSIS FOR THE TESTING PLANT

The factors considered during the design of this plant were;

**Major Considerations**

1 Component Selection (boiler, micro turbine and generator)

2 Fabrication (incinerator/combustion chamber, turbine and generator stand)

**General Considerations**

- Waste type
- Volume of waste
- Lagging material
- Insulation thickness
- Heat generation
- Construction
- Assembly
- Strength of materials
- Wear
- Corrosion
- Size and shape
- Cost
- Maintenance
- energy requirement
- Resistance to high pressure
- Resistance to high temperature
- Thermal conductivity
- Combustion process (air-fuel ratio)
- Electrical conductivity
- Heat losses
- Support devices, etc.

**(a) Incinerator**

Incinerator is a component used in burning municipal solid waste and other substances in high temperature which in turn generate heat which can be used for other purposes. It has different shapes ranging from rectangular, square-like, circular or round, etc.

The fabrication Machines involved in the fabrication processes were:

- Cutting machine
- Lathe operation
- Bending
- Welding
- Grinding

- ❖ Lagging
- ❖ Spraying Operation

**Cutting Operation**

Cutting machines are machines that are used in cutting materials in the machining shop. They are of types depending on the volume of materials to be cut. Grinding machine is a cutting machine that removes comparatively little quantity of materials from the parent material. Example, are the different types of saw; band saw, circular saw, diamond wire cutting, firewood processor, manual hacksaw and power hacksaw, punch press, ring saw, sizzix, swing saw, etc. The cutting operation was done to get the different sizes of the part of the incinerator to be fabricated. Also, cutting operation was applied in the cutting of the angle iron bars for the turbine and the generator stand.

**Lathe Operation**

This is the component that used in arranging workpiece to the desired shapes and size. This rotates a workpiece on the axis for the work to be done. The general work involve facing, knurling, deformation, etc.

**Welding operation**

For the purpose of his project, oxy-acetylene welding and electric arc welding was used together to achieve some goals.

**Lagging Operation**

Lagging is the finishing material (steel or aluminium, fibreglass, clay, cellulose, etc) used in order to reduce lost of heat to the environment.

**Finishing processes**

This involved processes such as surface smoothing and removal of rough edges, brushing and painting.

**Tools and Materials Required for the Fabrication**

In the course of this project various engineering tools and materials were employed, these include; steel rule, measuring tape, scriber, try square, center punch, hacksaw, hammer and spanners. The following machine tools were used; welding machine and its accessories, drilling machine and spraying machine. in course of the project, consumable materials that were used include mild steel sheets, 2inch pipes, welding electrodes, soft solders, soldering flux, assorted bolts, nuts, and screws, brushes, 1l inch angle bars, varnish, paint, 1.5 gauge coil wire and flexible wires.

**Mainframe construction:** the mainframe of the machine is the support at which all other machine components are mounted on. The material used in its construction was angular bar of 20mm (mild steel) this was chosen in order to give enough support to the machine during operation also to reduce weight of the machine and vibration. The joining of the mainframe involved measuring and cutting off the angular bar to the appropriate dimension and then welding the bar together to from the component in fig. above. Dimension of the mainframe are as follow. See Appendix 1

**Bearing selection**

Two rolling contact bearing were selected and mounted on the drive shaft in order to withstand the load imposed on the machine. This bearing was chosen because of its ability to withstand momentary shock loads and accuracy in shaft alignment. Also, it is reliable in service has low cost of maintenance and easy to mount on the shaft.

**Assembly Process**

In all the three main points of the cassava system machine which include the feed hopper, sifting chamber and the power unit were assembled together by welding and mechanical fastening using bolts and nuts. The mechanical fastening was to enable easy access to the internal components of the machine such as the brushes and sifting mesh maintenance and repairs purposes.

- **Convenient features (Ergonomics):** All the part was loaded at convenient position for ease of operation and control.
- Type of load and stresses caused by the load being stress on the driver shaft, shear stress on the driver shaft, radial load on the drive shaft etc.
- **Use of standard parts:** The parts and parameters were chosen according to Indian standard ranging
- **Maintenance:** cleaning and lubrication of machine parts are easy. In addition it is easy to replace any damaged part by the service personnel because of the simplicity of the machine.

**Tools and materials**

In the course of this project various engineering tools and materials were employed, these include; steel rule, measuring tape, scriber, try square, center punch, hacksaw, hammer and spanners. The following machine tools were used; welding machine and its accessories, drilling machine and spraying machine. in course of the project, consumable materials that were used include mild steel sheets, 2inch pipes, welding electrodes, soft solders, soldering flux, assorted bolts, nuts, and screws, brushes, 11 inch angle bars, varnish, paint, 1.5 gauge coil wire and flexible wires.

**(a) Boiler**

A boiler can be described as a device for creating steam by the used of heat energy to liquid. Liquid in this case, water. For the purpose of this research and for the testing plant, steam boiler selection will be adopted, taking into consideration the expected temperature and pressure required. Also taking into consideration, the quantity of MSW to be used as fuel.

**(b) Turbine**

This component converts the steam produce at high temperature and pressure to mechanical energy (rotary motion). Which invariably create an electromotive force in the generator. For the purpose of this research and for the testing plant, steam turbine selection will be adopted, taking into consideration the expected temperature and pressure required. Also taking into consideration, the quantity of MSW to be used as fuel.

**(c) Generator**

A generator is a component that convert rotary energy to electrical energy by creating an electromotive force in the electric field. The origin of this energy in this case is a mechanical energy from the burnt MSW in the combustion chamber. For this research and for the testing plant, electrical generator selection will be adopted, taking into consideration the expected power output expected to derive from the MSW which is used as fuel.

Table 3.1 Materials Required for the Fabrication Process:

| S/N | Parts | Materials used |
|---|---|---|
| 1 | Incinerator (Combustion chamber) | Mild steel |
| 2 | Boiler support | Mild Steel |
| 3 | Boiler | Stainless Steel |
| 4 | Micro turbine | Cast Iron |
| 5 | Generator | Cast Iron with Wind |
| 6 | Steam pipe | Mild Steel |
| 7 | Concrete slap | Alloy Rubber |
| 8 | Micro turbine and Generator stand | Mild Steel |
| 9 | Incinerator stand | Stainless Steel |
| 10 | Gauges | (ball bearing) Cast Iron |
| 11 | Pressure valve | Stainless Steel |

See Appendix 1: BEME

### 3.13 Design of municipal solid waste power plant

This is mainly a 3-D drawing of the municipal solid waste plant. See appendix 2.

## 3.14 EMISSION

Emission characterization and date were source from literature search. Municipal solid waste, generally, is a big class of waste component. In which the classes have other sub –type, etc. For this research, the municipal solid waste is grouped as follows:

- Organic
- Textiles wood and leather
- Paper-carton
- Plastics
- Metals
- Glass
- Inert matter
- Others

Considering organic waste for the emission analysis; the waste have different sub constituents that emit different types of emissions, though there are predominantly major emission associated with this type of waste.

Taking plastics into consideration for the same analysis, the outcome still follow the same path as the plastics are of so many types and all have different emission components due to their constituent elements.

Presently, there are still predominant emission associated with plastics combustion which much attentions are given with regards to greenhouse gas emission.

Other types of municipal solid waste follow these path.

Much consideration will be given to the municipal solid waste that frequently produces less quantity of effluent during combustion to mix with the municipal solid waste that frequently produce higher or more toxic emissions. This reason is to bring down the quantity of emission from the municipal solid waste with higher emission and sometimes toxic but have a higher calorific value.

# CHAPTER FOUR

## 4.0 RESULTS AND DISCUSSION

Table 4.1**:** Volume of municipal solid waste (MSW) generated from Uyo metropolis measured in Kilogram

| MSW | As at November/December 2014 |
|---|---|
| Volume | 72,000000 |

Source: AkwaIbom State Environmental and Waste Management Agency.

Table 4.2 Volume of municipal solid waste disposed in Uyo metropolis in kilogram for November/December 2014

| MSW | Per year |
|---|---|
| Volume | 3600000 |

Source:AkwaIbom State Environmental and Waste Management Agency.

Sample of certain quantity of MSW was measured on daily basis and sorted in order to know the main components of MSW in Uyo metropolis. From the research, the main components of the MSW in Uyo are:

(1) Organic
(2) Paper-Carton
(3) Glass
(4) Plastics
(5) Iron and metal packaging
(6) Textiles, wood, leather and elastics
(7) Inert matter
(8) Others.

Using the bomb calorimeter, the calorific value of the major components of MSW in Uyo were as follow:

Quantity of MSW generated in Uyo metropolis per year in tones = 72,000 Tonnes/year.

From the quantity measured on daily basis, the average percentage of the component present in municipal solid waste are as listed below:

Table 4.3 Showing percentage composition per kilogram and calorific value (CV) of each component in a location

| Sample (100kg) | Organic | | Paper-carton | | Glass | | Plastics | | Total |
|---|---|---|---|---|---|---|---|---|---|
| Locations | Weight %/Kg | CV-MJ | Weight- %/Kg | CV-MJ | Weight- %/Kg | CV-MJ | Weight- %/ Kg | CV-MJ | Weight %/Kg |
| 1 | 66.3 | 18.00 | 18.40 | 17.00 | 1.30 | 0.00 | 5.20 | 40.01 | 91.20 |
| 2 | 66.5 | 18.11 | 18.40 | 17.00 | 1.30 | 0.00 | 4.20 | 40.20 | 90.60 |
| 3 | 66.4 | 18.21 | 18.10 | 17.01 | 1.40 | 0.00 | 4.60 | 40.00 | 90.50 |
| 4 | 66.3 | 17.98 | 18.30 | 16.99 | 1.50 | 0.00 | 6.00 | 40.00 | 92.10 |
| 5 | 66.3 | 18.00 | 18.40 | 17.20 | 1.20 | 0.00 | 5.40 | 39.98 | 91.30 |
| 6 | 66.2 | 17.97 | 18.50 | 17.30 | 1.10 | 0.00 | 5.20 | 39.96 | 91.00 |
| 7 | 66.4 | 17.99 | 18.60 | 16.80 | 1.30 | 0.00 | 4.00 | 39.00 | 90.30 |
| 8 | 63.3 | 18.00 | 18.40 | 16.70 | 1.30 | 0.00 | 4.80 | 41.09 | 87.80 |
| 9 | 66.2 | 18.00 | 18.40 | 17.00 | 1.20 | 0.00 | 6.50 | 40.00 | 92.30 |
| 10 | 66.2 | 18.11 | 18.30 | 17.00 | 1.30 | 0.00 | 6.10 | 40.00 | 91.90 |
| Total | 663.1 | 180.26 | 184.8 | 170.00 | 12.90 | 0.00 | 52.00 | 400.24 | |
| Mean | 66.30 | 18.02 | 18.40 | 17.00 | 1.30 | 0.00 | 5.20 | 40.02 | |

Table 4.3 Showing percentage composition per kilogram and calorific value (CV) of each component in a location continued

| Sample (100kg) | Iron and metal | | Textiles/wood & Leather | | Inert matter | | Others | | Total |
|---|---|---|---|---|---|---|---|---|---|
| Locations | Weight-%/Kg | CV-MJ | Weight %/Kg | CV-MJ | Weight-%/Kg | CV-MJ | Weight-%/Kg | CV-MJ | Weight-%/kg |
| 1 | 2.00 | 0.00 | 4.30 | 32.00 | 0.50 | 0.00 | 2.00 | 18.00 | 8.80 |
| 2 | 2.90 | 0.00 | 3.50 | 32.20 | 0.40 | 0.00 | 2.60 | 18.00 | 9.40 |
| 3 | 3.00 | 0.00 | 5.10 | 31.90 | 0.20 | 0.00 | 1.20 | 18.60 | 9.50 |
| 4 | 1.00 | 0.00 | 3.10 | 31.80 | 1.30 | 0.00 | 2.50 | 18.40 | 7.90 |
| 5 | 0.10 | 0.00 | 6.40 | 32.10 | 1.30 | 0.00 | 0.90 | 17.40 | 8.70 |
| 6 | 1.10 | 0.00 | 7.10 | 32.20 | 0.10 | 0.00 | 0.70 | 17.60 | 9.00 |
| 7 | 1.10 | 0.00 | 3.90 | 31.80 | 0.20 | 0.00 | 4.50 | 18.01 | 9.70 |
| 8 | 8.90 | 0.00 | 0.10 | 32.01 | 0.10 | 0.00 | 0.10 | 17.99 | 9.20 |
| 9 | 0.10 | 0.00 | 6.50 | 32.00 | 0.80 | 0.00 | 0.30 | 18.00 | 7.70 |
| 10 | 0.60 | 0.00 | 7.20 | 31.99 | 0.10 | 0.00 | 0.20 | 18.00 | 8.10 |
| Total | 20.07 | 0.00 | 47.20 | 319.80 | 5.00 | 0.00 | 19.00 | 180.00 | |
| Mean | 2.10 | 0.00 | 4.30 | 32.00 | 0.5 | 0.00 | 1.90 | 18.00 | |

Table 4.4 Average Percentage of waste per kilogram of MSW

| S/N | Component | % per Kg |
|---|---|---|
| 1 | Organic | 66.3 |
| 2 | Paper-Carton | 18.4 |
| 3 | Plastics | 5.2 |
| 4 | Glass | 1.3 |
| 5 | Iron and metal packaging | 2.1 |
| 6 | Textiles, Wood, Leather and Elastics | 4.3 |
| 7 | Others | 1.9 |
| 8 | Inert matter | 0.5 |
| | Total | 100 |

Table 4.5 Calorific value of different waste - Experimental Results

| S/N | Component | Calorific Value (MJ/Kg) dry matter |
|---|---|---|
| 1 | Organic | 18 |
| 2 | Paper-Carton | 17 |
| 3 | Glass | 0 |
| 4 | Plastics | 40 |
| 5 | Iron and metal packaging | 0 |
| 6 | Textiles, Wood, Leather and Elastics | 32 |
| 7 | Inert matter | 0 |
| 8 | Others | 18 |

## 4.1 STATISTICAL ANALYSIS OF EXPERIMENTAL RESULTS

Table 4.6: Showing Experimental Results for OW/PCW at 9:1 mix

| I | $x_i$ | $\bar{x}$ | $x_i$- $\bar{x}$ | $(x_i - \bar{x})2$ |
|---|---|---|---|---|
| 1 | 18.71 | 17.90 | 0.81 | 0.6561 |
| 2 | 17.72 | 17.90 | -0.18 | 0.0324 |
| 3 | 17.81 | 17.90 | -0.09 | 0.0081 |
| 4 | 18.29 | 17.90 | 0.39 | 0.1521 |
| 5 | 17.48 | 17.90 | -0.42 | 0.1764 |
| 6 | 17.43 | 17.90 | -0.47 | 0.2209 |
| 7 | 17.38 | 17.90 | -0.52 | 0.2704 |
| 8 | 16.95 | 17.90 | -0.95 | 0.9025 |
| 9 | 18.66 | 17.90 | 0.76 | 0.5776 |
| 10 | 18.47 | 17.90 | 0.57 | 0.3249 |
| 11 | 17.80 | 17.90 | -0.10 | 0.0100 |
| 12 | 18.86 | 17.90 | 0.96 | 0.9216 |
| 13 | 17.31 | 17.90 | -0.59 | 0.3481 |
| 14 | 18.18 | 17.90 | 0.28 | 0.0784 |
| 15 | 17.48 | 17.90 | -0.42 | 0.1764 |
| 16 | 18.66 | 17.90 | 0.76 | 0.5776 |
| 17 | 17.14 | 17.90 | -0.76 | 0.5776 |
| 18 | 18.21 | 17.90 | 0.31 | 0.0961 |
| 19 | 18.69 | 17.90 | 0.79 | 0.6241 |
| 20 | 18.42 | 17.90 | 0.52 | 0.2704 |
| 21 | 18.90 | 17.90 | -0.30 | 0.0900 |

| | | | | |
|---|---|---|---|---|
| 22 | 17.46 | 17.90 | -0.44 | 0.1936 |
| 23 | 18.89 | 17.90 | 0.99 | 0.9804 |
| 24 | 18.23 | 17.90 | 0.33 | 0.1089 |
| 25 | 16.98 | 17.90 | -0.92 | 0.8464 |
| 26 | 17.06 | 17.90 | -0.84 | 0.7056 |
| 27 | 18.41 | 17.90 | 0.51 | 0.2601 |
| 28 | 18.46 | 17.90 | 0.56 | 0.3136 |
| 29 | 17.02 | 17.90 | -0.88 | 0.7744 |
| 30 | 17.99 | 17.90 | 0.09 | 0.0081 |
| 31 | 18.24 | 17.90 | 0.34 | 0.1156 |
| 32 | 18.48 | 17.90 | 0.58 | 0.3364 |
| 33 | 17.09 | 17.90 | -0.81 | 0.6561 |
| 34 | 17.51 | 17.90 | -0.39 | 0.1521 |
| 35 | 17.26 | 17.90 | -0.64 | 0.4096 |
| | 627.63 | | | 12.9526 |

Table 4.7: Showing Experimental Results for TLWW/PCW at 9:1 mix

| I | $x_i$ | $\bar{x}$ | $x_i$- $\bar{x}$ | $(x_i - \bar{x})2$ |
|---|---|---|---|---|
| 1 | 31.15 | 30.5 | 0.65 | 0.4325 |
| 2 | 30.58 | 30.5 | 0.08 | 0.1640 |
| 3 | 30.25 | 30.5 | -0.25 | 0.0625 |
| 4 | 30.68 | 30.5 | 0.18 | 0.0324 |
| 5 | 30.24 | 30.5 | -0.26 | 0.0676 |
| 6 | 29.65 | 30.5 | -0.85 | 0.7225 |
| 7 | 31.41 | 30.5 | 0.91 | 0.8281 |
| 8 | 30.63 | 30.5 | -0.87 | 0.7569 |
| 9 | 31.46 | 30.5 | 0.96 | 0.9216 |
| 10 | 29.82 | 30.5 | -0.68 | 0.4624 |
| 11 | 30.88 | 30.5 | 0.38 | 0.1444 |
| 12 | 31.30 | 30.5 | 0.80 | 0.6400 |
| 13 | 29.59 | 30.5 | -0.91 | 0.8281 |
| 14 | 29.95 | 30.5 | -0.53 | 0.2909 |
| 15 | 31.24 | 30.5 | 0.74 | 0.5476 |
| 16 | 31.20 | 30.5 | 0.70 | 0.4900 |
| 17 | 30.12 | 30.5 | -0.38 | 0.1644 |
| 18 | 30.31 | 30.5 | -0.19 | 0.0361 |
| 19 | 31.11 | 30.5 | 0.61 | 0.3721 |
| 20 | 29.71 | 30.5 | -0.79 | 0.6241 |
| 21 | 30.85 | 30.5 | 0.35 | 0.1225 |
| 22 | 31.47 | 30.5 | 0.97 | 0.9409 |
| 23 | 30.39 | 30.5 | -0.11 | 0.0121 |

| | | | | |
|---|---|---|---|---|
| 24 | 31.33 | 30.5 | 0.83 | 0.6889 |
| 25 | 29.81 | 30.5 | -0.67 | 0.4761 |
| 26 | 31.07 | 30.5 | 0.57 | 0.3249 |
| 27 | 31.05 | 30.5 | 0.55 | 0.3025 |
| 28 | 31.21 | 30.5 | 0.71 | 0.5041 |
| 29 | 30.14 | 30.5 | -0.36 | 0.1296 |
| 30 | 30.51 | 30.5 | 0.01 | 0.0001 |
| 31 | 29.55 | 30.5 | -0.95 | 0.9025 |
| 32 | 30.16 | 30.5 | -0.34 | 0.1156 |
| 33 | 29.58 | 30.5 | -0.92 | 0.8464 |
| 34 | 30.75 | 30.5 | 0.25 | 0.0625 |
| 35 | 31.08 | 30.5 | 0.58 | 0.3364 |
| | 1069.25 | | | 14.1557 |

Table 4.8: Showing Experimental Results for OW/PCW at 6:4 mix

| I | $x_i$ | $\bar{x}$ | $x_i$- $\bar{x}$ | $(x_i - \bar{x})2$ |
|---|---|---|---|---|
| 1 | 17.72 | 17.6 | 0.12 | 0.0144 |
| 2 | 17.48 | 17.6 | -0.12 | 0.0144 |
| 3 | 17.76 | 17.6 | 0.16 | 0.02.56 |
| 4 | 18.29 | 17.6 | 0.69 | 0.4761 |
| 5 | 17.73 | 17.6 | 0.13 | 0.0169 |
| 6 | 17.32 | 17.6 | -0.28 | 0.0784 |
| 7 | 17.56 | 17.6 | -0.04 | 0.0016 |
| 8 | 17.43 | 17.6 | -0.17 | 0.0289 |
| 9 | 16.89 | 17.6 | -0.71 | 0.5041 |
| 10 | 18.03 | 17.6 | 0.43 | 0.1849 |
| 11 | 18.43 | 17.6 | 0.83 | 0.6889 |
| 12 | 17.57 | 17.6 | -0.03 | 0.0009 |
| 13 | 17.33 | 17.6 | -0.27 | 0.0729 |
| 14 | 16.61 | 17.6 | -0.56 | 0.3136 |
| 15 | 18.59 | 17.6 | 0.98 | 0.9604 |
| 16 | 17.22 | 17.6 | -0.38 | 0.1444 |
| 17 | 17.58 | 17.6 | -0.02 | 0.0004 |
| 18 | 17.35 | 17.6 | -0.25 | 0.0625 |
| 19 | 17.53 | 17.6 | -0.07 | 0.0049 |
| 20 | 18.23 | 17.6 | 0.63 | 0.3969 |
| 21 | 16.76 | 17.6 | -0.84 | 0.7056 |
| 22 | 18.56 | 17.6 | 0.96 | 0.9216 |
| 23 | 16.88 | 17.6 | -0.72 | 0.5184 |

| | | | | |
|---|---|---|---|---|
| 24 | 17.44 | 17.6 | -0.16 | 0.0256 |
| 25 | 18.47 | 17.6 | 0.87 | 0.7569 |
| 26 | 16.84 | 17.6 | -0.76 | 0.5776 |
| 27 | 18.57 | 17.6 | 0.97 | 0.9409 |
| 28 | 17.22 | 17.6 | -0.38 | 0.1444 |
| 29 | 16.68 | 17.6 | -0.92 | 0.8464 |
| 30 | 18.50 | 17.6 | 0.90 | 0.8100 |
| 31 | 16.90 | 17.6 | -0.70 | 0.4900 |
| 32 | 18.40 | 17.6 | 0.80 | 0.6400 |
| 33 | 17.42 | 17.6 | -0.18 | 0.0324 |
| 34 | 17.47 | 17.6 | -0.13 | 0.0169 |
| 35 | 17.48 | 17.6 | -0.12 | 0.0144 |
| | 616.23 | | | 11.4322 |

Table 4.9: Showing Experimental Results for TLWW/PCW at 6:4 mix

| I | $x_i$ | $\bar{x}$ | $x_i$- $\bar{x}$ | $(x_i - \bar{x})2$ |
|---|---|---|---|---|
| 1 | 26.04 | 26.0 | 0.04 | 0.0016 |
| 2 | 26.44 | 26.0 | 0.44 | 0.1936 |
| 3 | 25.15 | 26.0 | -0.85 | 0.7225 |
| 4 | 25.50 | 26.0 | -0.50 | 0.2500 |
| 5 | 26.47 | 26.0 | 0.47 | 0.2209 |
| 6 | 26.83 | 26.0 | 0.83 | 0.6889 |
| 7 | 25.73 | 26.0 | -0.27 | 0.0729 |
| 8 | 25.79 | 26.0 | -0.21 | 0.0441 |
| 9 | 25.77 | 26.0 | 0.23 | 0.0529 |
| 10 | 26.93 | 26.0 | 0.93 | 0.8649 |
| 11 | 25.41 | 26.0 | -0.59 | 0.3481 |
| 12 | 25.76 | 26.0 | -0.24 | 0.0576 |
| 13 | 26.04 | 26.0 | 0.04 | 0.0016 |
| 14 | 26.76 | 26.0 | 0.76 | 0.5776 |
| 15 | 25.11 | 26.0 | -0.89 | 0.7921 |
| 16 | 26.73 | 26.0 | 0.73 | 0.5329 |
| 17 | 26.91 | 26.0 | 0.91 | 0.8281 |
| 18 | 25.69 | 26.0 | -0.31 | 0.0961 |
| 19 | 25.32 | 26.0 | -0.68 | 0.4624 |
| 20 | 25.16 | 26.0 | -0.85 | 0.7225 |
| 21 | 26.94 | 26.0 | 0.94 | 0.8836 |
| 22 | 25.27 | 26.0 | -0.73 | 0.5329 |
| 23 | 26.34 | 26.0 | 0.34 | 0.1156 |

| | | | | |
|---|---|---|---|---|
| 24 | 26.03 | 26.0 | 0.03 | 0.0009 |
| 25 | 25.32 | 26.0 | -0.68 | 0.4624 |
| 26 | 26.39 | 26.0 | 0.39 | 0.1521 |
| 27 | 26.63 | 26.0 | 0.63 | 0.3969 |
| 28 | 25.14 | 26.0 | -0.86 | 0.7396 |
| 29 | 26.68 | 26.0 | 0.68 | 0.4624 |
| 30 | 25.68 | 26.0 | -0.32 | 0.1024 |
| 31 | 26.53 | 26.0 | 0.53 | 0.2809 |
| 32 | 25.70 | 26.0 | -0.30 | 0.0900 |
| 33 | 25.59 | 26.0 | -0.41 | 0.1681 |
| 34 | 26.19 | 26.0 | 0.19 | 0.0361 |
| 35 | 26.44 | 26.0 | 0.44 | 0.1936 |
| | 910.41 | | | 12.0332 |

Table 4.10: Showing Experimental Results for PW/OW at 6:4 mix

| I | $x_i$ | $\bar{x}$ | $x_i$- $\bar{x}$ | $(x_i - \bar{x})2$ |
|---|---|---|---|---|
| 1 | 32.11 | 31.2 | 0.91 | 0.8281 |
| 2 | 30.46 | 31.2 | -0.74 | 0.5476 |
| 3 | 31.86 | 31.2 | 0.66 | 0.4356 |
| 4 | 30.22 | 31.2 | -0.98 | 0.9604 |
| 5 | 30.85 | 31.2 | -0.35 | 0.1225 |
| 6 | 31.55 | 31.2 | -0.65 | 0.4225 |
| 7 | 31.45 | 31.2 | 0.25 | 0.0625 |
| 8 | 31.85 | 31.2 | 0.65 | 0.4225 |
| 9 | 31.59 | 31.2 | 0.39 | 0.1521 |
| 10 | 30.86 | 31.2 | -0.34 | 0.1156 |
| 11 | 30.66 | 31.2 | -0.54 | 0.2916 |
| 12 | 31.98 | 31.2 | 0.78 | 0.6084 |
| 13 | 31.73 | 31.2 | 0.53 | 0.2809 |
| 14 | 30.39 | 31.2 | -0.81 | 0.6561 |
| 15 | 30.70 | 31.2 | -0.50 | 0.2500 |
| 16 | 31.77 | 31.2 | 0.57 | 0.3249 |
| 17 | 31.86 | 31.2 | 0.66 | 0.4356 |
| 18 | 30.59 | 31.2 | -0.61 | 0.3721 |
| 19 | 31.10 | 31.2 | -0.10 | 0.0100 |
| 20 | 30.97 | 31.2 | -0.23 | 0.0529 |
| 21 | 30.71 | 31.2 | -0.49 | 0.2401 |
| 22 | 31.60 | 31.2 | 0.40 | 0.1600 |
| 23 | 31.95 | 31.2 | 0.75 | 0.5625 |

| | | | | |
|---|---|---|---|---|
| 24 | 30.83 | 31.2 | -0.37 | 0.1369 |
| 25 | 30.24 | 31.2 | -0.96 | 0.9216 |
| 26 | 32.09 | 31.2 | 0.89 | 0.7921 |
| 27 | 31.90 | 31.2 | 0.70 | 0.4900 |
| 28 | 30.23 | 31.2 | -0.97 | 0.9409 |
| 29 | 31.84 | 31.2 | -0.64 | 0.4096 |
| 30 | 31.50 | 31.2 | 0.30 | 0.0900 |
| 31 | 30.64 | 31.2 | -0.56 | 0.3136 |
| 32 | 30.76 | 31.2 | -0.44 | 0.1936 |
| 33 | 32.02 | 31.2 | -0.82 | 0.6724 |
| 34 | 31.59 | 31.2 | 0.39 | 0.1521 |
| 35 | 30.26 | 31.2 | -0.94 | 0.8836 |
| | 1092.71 | | | 14.3109 |

Table 4.11: Showing Experimental Results for TLWW/OW at 9:1 mix

| I | $x_i$ | $\bar{x}$ | $x_i$- $\bar{x}$ | $(x_i - \bar{x})2$ |
|---|---|---|---|---|
| 1 | 31.38 | 30.6 | 0.78 | 0.6084 |
| 2 | 31.00 | 30.6 | 0.40 | 0.1600 |
| 3 | 31.59 | 30.6 | -0.99 | 0.9801 |
| 4 | 29.73 | 30.6 | -0.87 | 0.7569 |
| 5 | 31.07 | 30.6 | 0.47 | 0.2209 |
| 6 | 30.61 | 30.6 | -0.99 | 0.7225 |
| 7 | 30.01 | 30.6 | -0.59 | 0.3481 |
| 8 | 30.71 | 30.6 | 0.11 | 0.0121 |
| 9 | 30.90 | 30.6 | 0.30 | 0.0900 |
| 10 | 29.73 | 30.6 | -0.87 | 0.7569 |
| 11 | 31.23 | 30.6 | 0.63 | 0.3969 |
| 12 | 30.39 | 30.6 | -0.21 | 0.0441 |
| 13 | 30.61 | 30.6 | 0.01 | 0.0001 |
| 14 | 31.49 | 30.6 | 0.89 | 0.7921 |
| 15 | 30.18 | 30.6 | -0.42 | 0.1764 |
| 16 | 30.51 | 30.6 | -0.09 | 0.0081 |
| 17 | 31.36 | 30.6 | 0.76 | 0.5476 |
| 18 | 30.48 | 30.6 | -0.12 | 0.0144 |
| 19 | 30.10 | 30.6 | -0.50 | 0.2500 |
| 20 | 30.66 | 30.6 | 0.06 | 0.0036 |
| 21 | 29.92 | 30.6 | -0.68 | 0.6400 |
| 22 | 29.79 | 30.6 | -0.81 | 0.6241 |
| 23 | 30.89 | 30.6 | 0.29 | 0.0841 |

| | | | | |
|---|---|---|---|---|
| 24 | 30.20 | 30.6 | -0.40 | 0.1600 |
| 25 | 30.07 | 30.6 | -0.53 | 0.2809 |
| 26 | 31.28 | 30.6 | 0.68 | 0.4624 |
| 27 | 29.69 | 30.6 | -0.91 | 0.8281 |
| 28 | 31.55 | 30.6 | 0.95 | 0.9025 |
| 29 | 30.63 | 30.6 | 0.03 | 0.0009 |
| 30 | 31.21 | 30.6 | -0.39 | 0.1521 |
| 31 | 30.78 | 30.6 | 0.18 | 0.0324 |
| 32 | 31.17 | 30.6 | 0.57 | 0.3249 |
| 33 | 29.96 | 30.6 | -0.64 | 0.4096 |
| 34 | 31.36 | 30.6 | 0.76 | 0.5776 |
| 35 | 29.98 | 30.6 | -0.62 | 0.3844 |
| | 1072.22 | | | 12.8952 |

Table 4.12: Showing Experimental Results for PW/TLWW at 6:4 mix

| I | $x_i$ | $\bar{x}$ | $x_i$- $\bar{x}$ | $(x_i - \bar{x})2$ |
|---|---|---|---|---|
| 1 | 37.23 | 36.8 | 0.42 | 0.1764 |
| 2 | 36.64 | 36.8 | -0.16 | 0.0256 |
| 3 | 36.08 | 36.8 | 0.88 | 0.7744 |
| 4 | 37.47 | 36.8 | 0.67 | 0.4489 |
| 5 | 36.30 | 36.8 | -0.50 | 0.2500 |
| 6 | 36.17 | 36.8 | -0.63 | 0.3969 |
| 7 | 36.98 | 36.8 | 0.18 | 0.0324 |
| 8 | 36.23 | 36.8 | 0.95 | 0.9025 |
| 9 | 36.23 | 36.8 | -0.57 | 0.3249 |
| 10 | 36.73 | 36.8 | -0.07 | 0.0049 |
| 11 | 37.36 | 36.8 | 0.56 | 0.3136 |
| 12 | 37.63 | 36.8 | 0.83 | 0.6889 |
| 13 | 36.54 | 36.8 | -0.26 | 0.0676 |
| 14 | 36.25 | 36.8 | -0.55 | 0.3025 |
| 15 | 36.05 | 36.8 | -0.75 | 0.5625 |
| 16 | 37.13 | 36.8 | 0.33 | 0.1089 |
| 17 | 37.26 | 36.8 | 0.46 | 0.2116 |
| 18 | 36.53 | 36.8 | -0.27 | 0.0729 |
| 19 | 36.12 | 36.8 | -0.68 | 0.4624 |
| 20 | 36.24 | 36.8 | 0.56 | 0.3136 |
| 21 | 36.07 | 36.8 | 0.73 | 0.5329 |
| 22 | 36.12 | 36.8 | -0.68 | 0.4624 |
| 23 | 37.25 | 36.8 | 0.45 | 0.2025 |

| | | | | |
|---|---|---|---|---|
| 24 | 36.11 | 36.8 | 0.69 | 0.4761 |
| 25 | 37.68 | 36.8 | -0.88 | 0.7744 |
| 26 | 36.32 | 36.8 | -0.48 | 0.2304 |
| 27 | 36.18 | 36.8 | -0.62 | 0.3844 |
| 28 | 37.23 | 36.8 | 0.43 | 0.1849 |
| 29 | 37.47 | 36.8 | 0.67 | 0.4489 |
| 30 | 36.27 | 36.8 | -0.53 | 0.2809 |
| 31 | 37.65 | 36.8 | 0.85 | 0.7225 |
| 32 | 37.07 | 36.8 | 0.27 | 0.0729 |
| 33 | 36.57 | 36.8 | -0.23 | 0.0529 |
| 34 | 37.09 | 36.8 | 0.29 | 0.0841 |
| 35 | 36.16 | 36.8 | -0.64 | 0.4096 |
| | 1284.92 | | | 11.7612 |

Table 4.13: Showing Experimental Results for TLWW/OW at 6:4 mix

| i | $x_i$ | $\bar{x}$ | $x_i$- $\bar{x}$ | $(x_i - \bar{x})2$ |
|---|---|---|---|---|
| 1 | 26.49 | 26.4 | 0.09 | 0.0081 |
| 2 | 25.63 | 26.4 | -0.77 | 0.5929 |
| 3 | 26.86 | 26.4 | 0.46 | 0.2116 |
| 4 | 25.74 | 26.4 | -0.66 | 0.4356 |
| 5 | 26.77 | 26.4 | 0.37 | 0.1369 |
| 6 | 25.90 | 26.4 | -0.50 | 0.2500 |
| 7 | 26.18 | 26.4 | -0.22 | 0.0484 |
| 8 | 26.48 | 26.4 | 0.08 | 0.0064 |
| 9 | 26.77 | 26.4 | 0.37 | 0.1369 |
| 10 | 25.73 | 26.4 | -0.67 | 0.4489 |
| 11 | 27.27 | 26.4 | 0.87 | 0.7569 |
| 12 | 25.82 | 26.4 | -0.58 | 0.3364 |
| 13 | 26.30 | 26.4 | -0.30 | 0.0900 |
| 14 | 27.36 | 26.4 | 0.96 | 0.9216 |
| 15 | 26.08 | 26.4 | -0.32 | 0.1024 |
| 16 | 26.28 | 26.4 | -0.12 | 0.0144 |
| 17 | 25.77 | 26.4 | -0.63 | 0.3969 |
| 18 | 27.14 | 26.4 | 0.74 | 0.5476 |
| 19 | 27.03 | 26.4 | 0.63 | 0.3969 |
| 20 | 26.39 | 26.4 | -0.01 | 0.0001 |
| 21 | 25.90 | 26.4 | -0.50 | 0.2500 |
| 22 | 25.88 | 26.4 | -0.52 | 0.2704 |
| 23 | 26.21 | 26.4 | -0.19 | 0.0361 |

| | | | | |
|---|---|---|---|---|
| 24 | 25.89 | 26.4 | -0.51 | 0.2601 |
| 25 | 26.90 | 26.4 | 0.50 | 0.2500 |
| 26 | 26.27 | 26.4 | -0.13 | 0.0169 |
| 27 | 25.89 | 26.4 | -0.51 | 0.2601 |
| 28 | 25.44 | 26.4 | -0.96 | 0.9216 |
| 29 | 26.84 | 26.4 | 0.44 | 0.1936 |
| 30 | 27.35 | 26.4 | 0.95 | 0.9025 |
| 31 | 26.12 | 26.4 | -0.28 | 0.0784 |
| 32 | 26.98 | 26.4 | 0.58 | 0.3364 |
| 33 | 26.34 | 26.4 | -0.06 | 0.0036 |
| 34 | 25.54 | 26.4 | -0.86 | 0.7396 |
| 35 | 26.44 | 26.4 | 0.04 | 0.0016 |
| | 899.09 | | | 10.3604 |

Table 4.14: Showing Experimental Results for PW/PCW at 6:4 mix

| I | $x_i$ | $\bar{x}$ | $x_i$- $\bar{x}$ | $(x_i - \bar{x})2$ |
|---|---|---|---|---|
| 1 | 31.71 | 30.8 | 0.91 | 0.8281 |
| 2 | 30.06 | 30.8 | -0.74 | 0.5476 |
| 3 | 30.14 | 30.8 | -0.66 | 0.4356 |
| 4 | 31.78 | 30.8 | 0.98 | 0.9604 |
| 5 | 31.15 | 30.8 | 0.35 | 0.1225 |
| 6 | 30.15 | 30.8 | -0.65 | 0.4225 |
| 7 | 30.71 | 30.8 | -0.09 | 0.0081 |
| 8 | 30.05 | 30.8 | 0.25 | 0.0625 |
| 9 | 31.45 | 30.8 | 0.65 | 0.4225 |
| 10 | 30.41 | 30.8 | -0.39 | 0.1521 |
| 11 | 30.46 | 30.8 | -0.34 | 0.1156 |
| 12 | 30.96 | 30.8 | 0.16 | 0.0256 |
| 13 | 31.34 | 30.8 | 0.54 | 0.2916 |
| 14 | 31.61 | 30.8 | 0.81 | 0.6561 |
| 15 | 30.02 | 30.8 | -0.78 | 0.6084 |
| 16 | 30.27 | 30.8 | -0.53 | 0.2809 |
| 17 | 29.99 | 30.8 | -0.81 | 0.6561 |
| 18 | 31.30 | 30.8 | 0.50 | 0.2500 |
| 19 | 30.23 | 30.8 | -0.57 | 0.3249 |
| 20 | 31.46 | 30.8 | 0.66 | 0.4356 |
| 21 | 31.41 | 30.8 | 0.61 | 0.3721 |
| 22 | 30.90 | 30.8 | 0.10 | 0.0100 |

| | | | | |
|---|---|---|---|---|
| 23 | 30.57 | 30.8 | -0.23 | 0.0529 |
| 24 | 30.69 | 30.8 | -0.11 | 0.0121 |
| 25 | 31.29 | 30.8 | 0.49 | 0.2401 |
| 26 | 30.40 | 30.8 | -0.40 | 0.1600 |
| 27 | 31.55 | 30.8 | 0.75 | 0.5625 |
| 28 | 30.62 | 30.8 | -0.18 | 0.0324 |
| 29 | 31.17 | 30.8 | 0.37 | 0.1369 |
| 30 | 29.84 | 30.8 | -0.96 | 0.9216 |
| 31 | 31.69 | 30.8 | 0.89 | 0.7921 |
| 32 | 30.10 | 30.8 | -0.70 | 0.4900 |
| 33 | 31.77 | 30.8 | 0.97 | 0.9409 |
| 34 | 30.16 | 30.8 | -0.64 | 0.4096 |
| 35 | 31.10 | 30.8 | 0.30 | 0.0900 |
| | 30.8431 | | | 12.8299 |

Table 4.15: Showing Experimental Results for PW/PCW at 9:1 mix

| i | $x_i$ | $\bar{x}$ | $x_i$- $\bar{x}$ | $(x_i - \bar{x})2$ |
|---|---|---|---|---|
| 1 | 38.26 | 37.70 | 0.56 | 0.3136 |
| 2 | 38.48 | 37.70 | 0.78 | 0.6084 |
| 3 | 37.26 | 37.70 | -0.44 | 0.1936 |
| 4 | 36.95 | 37.70 | -0.75 | 0.5625 |
| 5 | 37.71 | 37.70 | 0.01 | 0.0001 |
| 6 | 36.84 | 37.70 | -0.86 | 0.7396 |
| 7 | 37.13 | 37.70 | -0.57 | 0.2800 |
| 8 | 38.38 | 37.70 | 0.68 | 0.4624 |
| 9 | 36.98 | 37.70 | -0.72 | 0.5184 |
| 10 | 37.54 | 37.70 | -0.16 | 0.0256 |
| 11 | 38.01 | 37.70 | 0.13 | 0.0961 |
| 12 | 37.79 | 37.70 | 0.09 | 0.0081 |
| 13 | 37.01 | 37.70 | -0.69 | 0.4761 |
| 14 | 38.53 | 37.70 | 0.83 | 0.6889 |
| 15 | 37.43 | 37.70 | -0.27 | 0.0729 |
| 16 | 37.50 | 37.70 | -0.20 | 0.0400 |
| 17 | 38.62 | 37.70 | 0.92 | 0.8464 |
| 18 | 38.42 | 37.70 | 0.72 | 0.5184 |
| 19 | 36.94 | 37.70 | -0.76 | 0.5776 |
| 20 | 37.84 | 37.70 | 0.14 | 0.0196 |
| 21 | 37.52 | 37.70 | -0.18 | 0.0324 |
| 22 | 37.08 | 37.70 | -0.62 | 0.3844 |
| 23 | 37.71 | 37.70 | 0.01 | 0.0001 |

| | | | | |
|---|---|---|---|---|
| 24 | 37.56 | 37.70 | -0.14 | 0.0196 |
| 25 | 37.64 | 37.70 | -0.06 | 0.0036 |
| 26 | 38.17 | 37.70 | 0.47 | 0.2209 |
| 27 | 36.83 | 37.70 | -0.87 | 0.7569 |
| 28 | 37.34 | 37.70 | -0.36 | 0.1296 |
| 29 | 37.51 | 37.70 | -0.19 | 0.0361 |
| 30 | 38.21 | 37.70 | 0.51 | 0.2601 |
| 31 | 37.61 | 37.70 | -0.09 | 0.0081 |
| 32 | 38.05 | 37.70 | 0.35 | 0.1225 |
| 33 | 36.83 | 37.70 | -0.87 | 0.7569 |
| 34 | 37.30 | 37.70 | -0.40 | 0.1600 |
| 35 | 37.99 | 37.70 | 0.29 | 0.0841 |
| | 1316.97 | | | 10.0685 |

Table 4.16: Showing Experimental Results for PW/TLWW at 9:1 mix

| I | $x_i$ | $\bar{x}$ | $x_i$- $\bar{x}$ | $(x_i - \bar{x})2$ |
|---|---|---|---|---|
| 1 | 39.34 | 39.20 | 0.14 | 0.0196 |
| 2 | 39.77 | 39.20 | 0.57 | 0.3249 |
| 3 | 39.09 | 39.20 | -0.11 | 0.0121 |
| 4 | 38.49 | 39.20 | -0.71 | 0.5041 |
| 5 | 39.90 | 39.20 | 0.70 | 0.4900 |
| 6 | 39.89 | 39.20 | 0.69 | 0.4761 |
| 7 | 38.54 | 39.20 | -0.66 | 0.4356 |
| 8 | 38.62 | 39.20 | -0.58 | 0.3364 |
| 9 | 39.48 | 39.20 | -0.28 | 0.0784 |
| 10 | 38.98 | 39.20 | -0.22 | 0.0484 |
| 11 | 39.31 | 39.20 | 0.11 | 0.0121 |
| 12 | 39.96 | 39.20 | 0.76 | 0.5776 |
| 13 | 39.10 | 39.20 | -0.10 | 0.0100 |
| 14 | 39.85 | 39.20 | 0.65 | 0.4225 |
| 15 | 38.33 | 39.20 | -0.87 | 0.7569 |
| 16 | 38.34 | 39.20 | -0.86 | 0.7396 |
| 17 | 38.93 | 39.20 | -0.27 | 0.0729 |
| 18 | 38.47 | 39.20 | -0.73 | 0.5329 |
| 19 | 38.76 | 39.20 | -0.44 | 0.1936 |
| 20 | 38.45 | 39.20 | -0.75 | 0.5625 |
| 21 | 40.00 | 39.20 | 0.80 | 0.6400 |
| 22 | 38.44 | 39.20 | -0.76 | 0.5776 |

| | | | | |
|---|---|---|---|---|
| 23 | 39.06 | 39.20 | -0.14 | 0.0196 |
| 24 | 39.64 | 39.20 | 0.44 | 0.1936 |
| 25 | 40.15 | 39.20 | 0.98 | 0.9025 |
| 26 | 38.50 | 39.20 | -0.70 | 0.4900 |
| 27 | 39.65 | 39.20 | 0.45 | 0.2025 |
| 28 | 39.41 | 39.20 | 0.21 | 0.0441 |
| 29 | 39.31 | 39.20 | 0.11 | 0.0121 |
| 30 | 39.01 | 39.20 | -0.19 | 0.0361 |
| 31 | 39.14 | 39.20 | -0.06 | 0.0036 |
| 32 | 39.18 | 39.20 | -0.03 | 0.0009 |
| 33 | 39.81 | 39.20 | 0.61 | 0.3721 |
| 34 | 39.31 | 39.20 | 0.11 | 0.0121 |
| 35 | 39.68 | 39.20 | 0.48 | 0.2304 |
| | 1371.89 | | | 10.3434 |

Table 4.17: Showing Experimental Results for PW/OW at 9:1 mix

| I | $x_i$ | $\bar{x}$ | $x_i$- $\bar{x}$ | $(x_i - \bar{x})2$ |
|---|---|---|---|---|
| 1 | 38.22 | 37.80 | 0.42 | 0.1764 |
| 2 | 38.24 | 37.80 | 0.44 | 0.1936 |
| 3 | 37.15 | 37.80 | -0.65 | 0.4225 |
| 4 | 38.89 | 37.80 | 0.84 | 0.7056 |
| 5 | 37.34 | 37.80 | -0.46 | 0.2116 |
| 6 | 37.02 | 37.80 | -0.78 | 0.6084 |
| 7 | 37.40 | 37.80 | -0.40 | 0.1600 |
| 8 | 38.58 | 37.80 | 0.78 | 0.6084 |
| 9 | 38.69 | 37.80 | 0.89 | 0.7921 |
| 10 | 37.09 | 37.80 | -0.71 | 0.5041 |
| 11 | 38.50 | 37.80 | 0.70 | 0.4900 |
| 12 | 37.73 | 37.80 | -0.07 | 0.0049 |
| 13 | 38.33 | 37.80 | 0.53 | 0.2809 |
| 14 | 37.25 | 37.80 | -0.55 | 0.3025 |
| 15 | 36.91 | 37.80 | -0.89 | 0.7921 |
| 16 | 37.87 | 37.80 | 0.07 | 0.0049 |
| 17 | 37.77 | 37.80 | -0.03 | 0.0009 |
| 18 | 37.92 | 37.80 | 0.12 | 0.0144 |
| 19 | 38.33 | 37.80 | 0.53 | 0.2809 |
| 20 | 37.01 | 37.80 | -0.79 | 0.6241 |
| 21 | 37.20 | 37.80 | -0.60 | 0.3600 |
| 22 | 37.62 | 37.80 | -0.18 | 0.0324 |

| | | | | |
|---|---|---|---|---|
| 23 | 38.26 | 37.80 | 0.46 | 0.2116 |
| 24 | 38.43 | 37.80 | 0.63 | 0.3969 |
| 25 | 37.27 | 37.80 | -0.53 | 0.2809 |
| 26 | 36.82 | 37.80 | -0.98 | 0.9604 |
| 27 | 38.09 | 37.80 | 0.29 | 0.0841 |
| 28 | 36.99 | 37.80 | -0.81 | 0.6561 |
| 29 | 38.23 | 37.80 | 0.43 | 0.1849 |
| 30 | 37.56 | 37.80 | -0.24 | 0.0576 |
| 31 | 37.29 | 37.80 | -0.51 | 0.2601 |
| 32 | 38.59 | 37.80 | 0.79 | 0.6241 |
| 33 | 37.67 | 37.80 | -0.13 | 0.0169 |
| 34 | 38.39 | 37.80 | 0.59 | 0.3481 |
| 35 | 37.58 | 37.80 | -0.22 | 0.0484 |
| | 1322.23 | | | 11.7008 |

Table 4.18: Showing Experimental Results for PW/TLWW/PCW at 5;4;1 mix

| I | $x_i$ | $\bar{x}$ | $x_i$- $\bar{x}$ | $(x_i - \bar{x})2$ |
|---|---|---|---|---|
| 1 | 34.47 | 34.5 | -0.03 | 0.0009 |
| 2 | 34.06 | 34.5 | -0.44 | 0.1936 |
| 3 | 34.01 | 34.5 | -0.49 | 0.2401 |
| 4 | 35.03 | 34.5 | 0.53 | 0.2809 |
| 5 | 35.16 | 34.5 | 0.66 | 0.4356 |
| 6 | 34.53 | 34.5 | 0.03 | 0.0009 |
| 7 | 34.38 | 34.5 | -0.12 | 0.0144 |
| 8 | 33.84 | 34.5 | -0.66 | 0.4356 |
| 9 | 35.33 | 34.5 | 0.83 | 0.6889 |
| 10 | 34.58 | 34.5 | -0.02 | 0.0004 |
| 11 | 34.32 | 34.5 | -0.28 | 0.0784 |
| 12 | 35.50 | 34.5 | 0.90 | 0.8100 |
| 13 | 34.15 | 34.5 | -0.35 | 0.1225 |
| 14 | 34.28 | 34.5 | -0.22 | 0.0484 |
| 15 | 36.26 | 34.5 | 0.76 | 0.6776 |
| 16 | 35.43 | 34.5 | 0.93 | 0.8649 |
| 17 | 34.47 | 34.5 | -0.03 | 0.0009 |
| 18 | 33.53 | 34.5 | -0.97 | 0.9409 |
| 19 | 34.79 | 34.5 | 0.29 | 0.0841 |
| 20 | 34.45 | 34.5 | -0.05 | 0.0025 |
| 21 | 34.10 | 34.5 | 0.40 | 0.1600 |
| 22 | 33.56 | 34.5 | -0.94 | 0.8836 |

| | | | | |
|---|---|---|---|---|
| 23 | 33.88 | 34.5 | -0.62 | 0.3844 |
| 24 | 33.69 | 34.5 | 0.81 | 0.6561 |
| 25 | 35.22 | 34.5 | 0.72 | 0.5184 |
| 26 | 35.26 | 34.5 | 0.76 | 0.5776 |
| 27 | 34.06 | 34.5 | -0.44 | 0.1936 |
| 28 | 34.26 | 34.5 | -0.24 | 0.0576 |
| 29 | 33.66 | 34.5 | -0.84 | 0.7056 |
| 30 | 35.03 | 34.5 | 0.53 | 0.2809 |
| 31 | 33.69 | 34.5 | 0.81 | 0.6561 |
| 32 | 34.77 | 34.5 | 0.27 | 0.0729 |
| 33 | 34.05 | 34.5 | -0.45 | 0.2025 |
| 34 | 33.89 | 34.5 | -0.61 | 0.3721 |
| 35 | 35.36 | 34.5 | 0.86 | 0.7396 |
| | 1207.05 | | | 12.2825 |

Table 4.19: Showing Experimental Results for PW/TLWW/OW at 5:4:1 mix

| I | $x_i$ | $\bar{x}$ | $x_i$- $\bar{x}$ | $(x_i - \bar{x})2$ |
|---|---|---|---|---|
| 1 | 33.82 | 34.60 | -0.78 | 0.6084 |
| 2 | 34.19 | 34.60 | -0.41 | 0.1681 |
| 3 | 33.92 | 34.60 | -0.68 | 0.4624 |
| 4 | 35.10 | 34.60 | 0.50 | 0.2500 |
| 5 | 34.60 | 34.60 | 0.00 | 0.0000 |
| 6 | 34.69 | 34.60 | 0.09 | 0.0081 |
| 7 | 35.51 | 34.60 | 0.91 | 0.8281 |
| 8 | 33.66 | 34.60 | -0.94 | 0.9400 |
| 9 | 35.23 | 34.60 | 0.63 | 0.3969 |
| 10 | 34.58 | 34.60 | -0.02 | 0.0004 |
| 11 | 34.63 | 34.60 | 0.03 | 0.0009 |
| 12 | 34.31 | 34.60 | -0.29 | 0.0841 |
| 13 | 33.76 | 34.60 | -0.84 | 0.7056 |
| 14 | 34.64 | 34.60 | 0.04 | 0.0400 |
| 15 | 34.41 | 34.60 | -0.19 | 0.0361 |
| 16 | 35.13 | 34.60 | 0.53 | 0.2809 |
| 17 | 33.67 | 34.60 | -0.93 | 0.8649 |
| 18 | 35.02 | 34.60 | 0.42 | 0.1764 |
| 19 | 34.20 | 34.60 | -0.40 | 0.1600 |
| 20 | 34.61 | 34.60 | 0.01 | 0.0001 |
| 21 | 35.58 | 34.60 | -0.98 | 0.9604 |
| 22 | 35.46 | 34.60 | 0.86 | 0.7396 |

| | | | | |
|---|---|---|---|---|
| 23 | 34.33 | 34.60 | -0.27 | 0.0729 |
| 24 | 35.32 | 34.60 | 0.72 | 0.5184 |
| 25 | 34.06 | 34.60 | -0.54 | 0.2916 |
| 26 | 34.34 | 34.60 | -0.26 | 0.0676 |
| 27 | 34.68 | 34.60 | 0.08 | 0.0064 |
| 28 | 34.71 | 34.60 | 0.11 | 0.0121 |
| 29 | 33.87 | 34.60 | -0.73 | 0.5329 |
| 30 | 34.92 | 34.60 | 0.32 | 0.1024 |
| 31 | 33.71 | 34.60 | -0.89 | 0.7921 |
| 32 | 35.24 | 34.60 | 0.64 | 0.4096 |
| 33 | 34.51 | 34.60 | -0.09 | 0.0081 |
| 34 | 25.09 | 34.60 | 0.49 | 0.2401 |
| 35 | 33.79 | 34.60 | -0.81 | 0.6561 |
| | 1209 | | | 11.4217 |

Table 4.20: Showing Experimental Results for PW/OW/PCW at 5:4:1 mix

| I | $x_i$ | $\bar{x}$ | $x_i$- $\bar{x}$ | $(x_i - \bar{x})2$ |
|---|---|---|---|---|
| 1 | 28.52 | 28.9 | -0.38 | 0.1444 |
| 2 | 28.64 | 28.9 | -0.26 | 0.0676 |
| 3 | 28.35 | 28.9 | 0.55 | 0.3025 |
| 4 | 29.78 | 28.9 | 0.88 | 0.7744 |
| 5 | 29.77 | 28.9 | 0.87 | 0.7569 |
| 6 | 29.68 | 28.9 | -0.78 | 0.6084 |
| 7 | 28.32 | 28.9 | -0.08 | 0.0064 |
| 8 | 29.11 | 28.9 | 0.21 | 0.0441 |
| 9 | 29.11 | 28.9 | 0.21 | 0.0441 |
| 10 | 29.04 | 28.9 | 0.14 | 0.0196 |
| 11 | 28.90 | 28.9 | 0.00 | 0.0000 |
| 12 | 28.74 | 28.9 | -0.16 | 0.0256 |
| 13 | 28.35 | 28.9 | -0.55 | 0.3025 |
| 14 | 29.66 | 28.9 | 0.76 | 0.5776 |
| 15 | 29.83 | 28.9 | 0.93 | 0.8649 |
| 16 | 28.00 | 28.9 | -0.90 | 0.8100 |
| 17 | 28.75 | 28.9 | -0.15 | 0.0225 |
| 18 | 28.00 | 28.9 | 0.00 | 0.0000 |
| 19 | 28.85 | 28.9 | -0.05 | 0.0025 |
| 20 | 28.45 | 28.9 | -0.45 | 0.2025 |
| 21 | 28.72 | 28.9 | -0.18 | 0.0324 |
| 22 | 29.19 | 28.9 | 0.29 | 0.0841 |

| | | | | |
|---|---|---|---|---|
| 23 | 29.53 | 28.9 | 0.63 | 0.3969 |
| 24 | 28.42 | 28.9 | -0.48 | 0.2304 |
| 25 | 28.88 | 28.9 | -0.04 | 0.0016 |
| 26 | 29.38 | 28.9 | 0.48 | 0.2304 |
| 27 | 29.23 | 28.9 | 0.33 | 0.1089 |
| 28 | 29.51 | 28.9 | 0.61 | 0.3721 |
| 29 | 28.67 | 28.9 | -0.23 | 0.0529 |
| 30 | 28.47 | 28.9 | -0.43 | 0.1849 |
| 31 | 28.75 | 28.9 | -0.15 | 0.0225 |
| 32 | 29.01 | 28.9 | 0.11 | 0.0121 |
| 33 | 28.53 | 28.9 | -0.37 | 0.1369 |
| 34 | 29.36 | 28.9 | 0.46 | 0.2116 |
| 35 | 28.18 | 28.9 | -0.72 | 0.5784 |
| | 1012.16 | | | |

Table 4.21: Showing Experimental Results for TLWW/OW/PCW at 5:4:1 mix

| I | $x_i$ | $\bar{x}$ | $x_i$- $\bar{x}$ | $(x_i - \bar{x})2$ |
|---|---|---|---|---|
| 1 | 25.68 | 24.9 | 0.78 | 0.6084 |
| 2 | 25.27 | 24.9 | 0.67 | 0.4489 |
| 3 | 24.23 | 24.9 | -0.67 | 0.4489 |
| 4 | 24.83 | 24.9 | -0.07 | 0.0049 |
| 5 | 24.12 | 24.9 | -0.78 | 0.6084 |
| 6 | 25.14 | 24.9 | 0.24 | 0.0576 |
| 7 | 24.54 | 24.9 | -0.36 | 0.1296 |
| 8 | 24.61 | 24.9 | -0.29 | 0.0841 |
| 9 | 25.82 | 24.9 | 0.92 | 0.8464 |
| 10 | 25.08 | 24.9 | 0.18 | 0.0324 |
| 11 | 23.92 | 24.9 | -0.98 | 0.9604 |
| 12 | 25.00 | 24.9 | -0.35 | 0.1225 |
| 13 | 24.95 | 24.9 | 0.05 | 0.0025 |
| 14 | 25.33 | 24.9 | 0.43 | 0.1849 |
| 15 | 25.34 | 24.9 | 0.44 | 0.1936 |
| 16 | 23.96 | 24.9 | -0.94 | 0.8836 |
| 17 | 24.27 | 24.9 | -0.63 | 0.3969 |
| 18 | 25.10 | 24.9 | 0.20 | 0.0400 |
| 19 | 25.52 | 24.9 | 0.62 | 0.3844 |
| 20 | 24.91 | 24.9 | 0.01 | 0.0001 |
| 21 | 24.46 | 24.9 | -0.44 | 0.1936 |
| 22 | 24.24 | 24.9 | -0.66 | 0.4356 |

| | | | | |
|---|---|---|---|---|
| 23 | 25.21 | 24.9 | 0.31 | 0.0961 |
| 24 | 25.53 | 24.9 | 0.63 | 0.3969 |
| 25 | 24.61 | 24.9 | -0.29 | 0.0841 |
| 26 | 24.86 | 24.9 | -0.04 | 0.1600 |
| 27 | 24.26 | 24.9 | -0.64 | 0.4096 |
| 28 | 25.18 | 24.9 | 0.28 | 0.0784 |
| 29 | 25.67 | 24.9 | 0.77 | 0.5929 |
| 30 | 24.74 | 24.9 | -0.16 | 0.0256 |
| 31 | 24.08 | 24.9 | -0.82 | 0.6724 |
| 32 | 25.59 | 24.9 | 0.69 | 0.4761 |
| 33 | 25.31 | 24.9 | 0.41 | 0.1681 |
| 34 | 24.37 | 24.9 | -0.53 | 0.2809 |
| 35 | 24.04 | 24.9 | -0.86 | 0.7396 |
| | 870.06 | | | 11.2484 |

Table 4.22: Showing Experimental Results for PW/TLWW/OW at 4:3:3 mix

| I | $x_i$ | $\bar{x}$ | $x_i$- $\bar{x}$ | $(x_i - \bar{x})2$ |
|---|---|---|---|---|
| 1 | 30.47 | 31.0 | -0.53 | 0.2809 |
| 2 | 30.45 | 31.0 | -0.55 | 0.3025 |
| 3 | 31.74 | 31.0 | 0.74 | 0.5476 |
| 4 | 31.52 | 31.0 | 0.52 | 0.2704 |
| 5 | 30.14 | 31.0 | -0.86 | 0.7396 |
| 6 | 30.28 | 31.0 | -0.72 | 0.5184 |
| 7 | 30.96 | 31.0 | -0.04 | 0.0016 |
| 8 | 31.57 | 31.0 | 0.57 | 0.3249 |
| 9 | 31.22 | 31.0 | 0.22 | 0.0484 |
| 10 | 31.82 | 31.0 | 0.82 | 0.6724 |
| 11 | 31.28 | 31.0 | 0.28 | 0.0784 |
| 12 | 30.26 | 31.0 | -0.74 | 0.5476 |
| 13 | 31.74 | 31.0 | 0.74 | 0.5476 |
| 14 | 31.76 | 31.0 | 0.76 | 0.5776 |
| 15 | 31.23 | 31.0 | 0.23 | 0.0529 |
| 16 | 31.09 | 31.0 | 0.09 | 0.0081 |
| 17 | 30.67 | 31.0 | -0.33 | 0.1089 |
| 18 | 30.16 | 31.0 | -0.84 | 0.7056 |
| 19 | 30.02 | 31.0 | -0.98 | 0.9604 |
| 20 | 31.89 | 31.0 | 0.89 | 0.7921 |
| 21 | 31.22 | 31.0 | 0.22 | 0.0484 |
| 22 | 30.14 | 31.0 | -0.86 | 0.7396 |

| | | | | |
|---|---|---|---|---|
| 23 | 30.03 | 31.0 | -0.97 | 0.9409 |
| 24 | 30.98 | 31.0 | -0.02 | 0.0004 |
| 25 | 31.04 | 31.0 | 0.04 | 0.0016 |
| 26 | 31.88 | 31.0 | 0.88 | 0.7744 |
| 27 | 31.27 | 31.0 | 0.27 | 0.0729 |
| 28 | 31.58 | 31.0 | 0.58 | 0.3364 |
| 29 | 30.37 | 31.0 | -0.63 | 0.3969 |
| 30 | 30.02 | 31.0 | -0.80 | 0.6400 |
| 31 | 30.60 | 31.0 | -0.40 | 0.1600 |
| 32 | 31.77 | 31.0 | 0.77 | 0.5929 |
| 33 | 31.27 | 31.0 | 0.27 | 0.0729 |
| 34 | 31.60 | 31.0 | 0.60 | 0.3600 |
| 35 | 30.37 | 31.0 | -0.63 | 0.3969 |
| | 1084.59 | | | 13.5901 |

Table 4.23: Showing Experimental Results for PW/OW/PCW at 4:3:3 mix

| I | $x_i$ | $\bar{x}$ | $x_i$- $\bar{x}$ | $(x_i - \bar{x})2$ |
|---|---|---|---|---|
| 1 | 27.38 | 26.5 | 0.88 | 0.7744 |
| 2 | 25.85 | 26.5 | -0.65 | 0.4225 |
| 3 | 25.86 | 26.5 | -0.64 | 0.4096 |
| 4 | 26.55 | 26.5 | 0.05 | 0.0025 |
| 5 | 27.06 | 26.5 | 0.56 | 0.3136 |
| 6 | 25.51 | 26.5 | -0.99 | 0.9801 |
| 7 | 26.27 | 26.5 | -0.23 | 0.0529 |
| 8 | 27.16 | 26.5 | 0.66 | 0.4356 |
| 9 | 26.54 | 26.5 | -0.04 | 0.0016 |
| 10 | 26.50 | 26.5 | 0.00 | 0.0000 |
| 11 | 26.50 | 26.5 | 0.00 | 0.0000 |
| 12 | 26.46 | 26.5 | -0.04 | 0.0016 |
| 13 | 25.62 | 26.5 | -0.88 | 0.7744 |
| 14 | 27.08 | 26.5 | 0.58 | 0.3364 |
| 15 | 27.27 | 26.5 | 0.77 | 0.5929 |
| 16 | 26.67 | 26.5 | 0.17 | 0.0289 |
| 17 | 26.18 | 26.5 | -0.32 | 0.1024 |
| 18 | 25.95 | 26.5 | -0.55 | 0.3025 |
| 19 | 26.26 | 26.5 | -0.24 | 0.0576 |
| 20 | 26.64 | 26.5 | 0.14 | 0.0196 |
| 21 | 27.18 | 26.5 | 0.68 | 0.4624 |
| 22 | 26.29 | 26.5 | -0.21 | 0.0441 |

| | | | | |
|---|---|---|---|---|
| 23 | 26.88 | 26.5 | 0.38 | 0.1444 |
| 24 | 27.18 | 26.5 | 0.68 | 0.4624 |
| 25 | 26.42 | 26.5 | -0.08 | 0.0064 |
| 26 | 25.95 | 26.5 | -0.55 | 0.3025 |
| 27 | 26.50 | 26.5 | 0.00 | 0.0000 |
| 28 | 26.20 | 26.5 | -0.30 | 0.0900 |
| 29 | 27.10 | 26.5 | 0.60 | 0.3600 |
| 30 | 27.14 | 26.5 | 0.64 | 0.4096 |
| 31 | 26.33 | 26.5 | -0.17 | 0.0289 |
| 32 | 25.89 | 26.5 | -0.61 | 0.3721 |
| 33 | 25.75 | 26.5 | -0.75 | 0.5625 |
| 34 | 27.06 | 26.5 | 0.56 | 0.3136 |
| 35 | 27.08 | 26.5 | 0.58 | 0.3364 |
| | 928.26 | | | 9.5017 |

Table 4.24: Showing Experimental Results for TLWW/OW/PCW at 4:3:3 mix

| I | $x_i$ | $\bar{x}$ | $x_i$- $\bar{x}$ | $(x_i - \bar{x})2$ |
|---|---|---|---|---|
| 1 | 22.32 | 23.30 | -0.98 | 0.9604 |
| 2 | 23.54 | 23.30 | 0.24 | 0.0576 |
| 3 | 24.10 | 23.30 | 0.80 | 0.6400 |
| 4 | 23.01 | 23.30 | -0.29 | 0.0841 |
| 5 | 22.70 | 23.30 | -0.60 | 0.3600 |
| 6 | 22.68 | 23.30 | -0.62 | 0.3844 |
| 7 | 23.81 | 23.30 | 0.51 | 0.2601 |
| 8 | 23.75 | 23.30 | 0.45 | 0.2025 |
| 9 | 23.31 | 23.30 | 0.01 | 0.0001 |
| 10 | 23.78 | 23.30 | 0.48 | 0.2304 |
| 11 | 22.34 | 23.30 | -0.96 | 0.9216 |
| 12 | 24.22 | 23.30 | 0.92 | 0.8464 |
| 13 | 22.52 | 23.30 | -0.78 | 0.6084 |
| 14 | 24.05 | 23.30 | 0.75 | 0.5625 |
| 15 | 23.07 | 23.30 | -0.23 | 0.0529 |
| 16 | 22.53 | 23.30 | -0.77 | 0.5929 |
| 17 | 23.27 | 23.30 | -0.03 | 0.0009 |
| 18 | 24.02 | 23.30 | 0.72 | 0.5184 |
| 19 | 24.15 | 23.30 | 0.85 | 0.7225 |
| 20 | 22.63 | 23.30 | -0.67 | 0.4489 |
| 21 | 23.15 | 23.30 | -0.15 | 0.0225 |
| 22 | 23.71 | 23.30 | 0.41 | 0.1681 |

| | | | | |
|---|---|---|---|---|
| 23 | 23.69 | 23.30 | 0.39 | 0.1521 |
| 24 | 22.68 | 23.30 | -0.62 | 0.3844 |
| 25 | 24.12 | 23.30 | 0.82 | 0.6724 |
| 26 | 22.73 | 23.30 | -0.57 | 0.3249 |
| 27 | 23.98 | 23.30 | 0.68 | 0.4624 |
| 28 | 22.42 | 23.30 | -0.88 | 0.7744 |
| 29 | 23.26 | 23.30 | -0.04 | 0.0016 |
| 30 | 24.17 | 23.30 | 0.87 | 0.7569 |
| 31 | 22.31 | 23.30 | -0.99 | 0.9801 |
| 32 | 24.21 | 23.30 | 0.91 | 0.8281 |
| 33 | 23.05 | 23.30 | -0.25 | 0.0625 |
| 34 | 23.45 | 23.30 | 0.15 | 0.0225 |
| 35 | 23.66 | 23.30 | 0.36 | 0.1296 |
| | 816.39 | | | 13.6098 |

Table 4.25 : Showing Experimental Results for PW/TLWW/PCW at 4:3:3 mix

| I | $x_i$ | $\bar{x}$ | $x_i$- $\bar{x}$ | $(x_i - \bar{x})2$ |
|---|---|---|---|---|
| 1 | 27.09 | 26.50 | 0.59 | 0.3481 |
| 2 | 26.69 | 26.50 | 0.19 | 0.0361 |
| 3 | 25.67 | 26.50 | -0.83 | 0.6889 |
| 4 | 27.01 | 26.50 | 0.51 | 0.2601 |
| 5 | 27.05 | 26.50 | 0.55 | 0.3025 |
| 6 | 25.70 | 26.50 | -0.80 | 0.6400 |
| 7 | 25.80 | 26.50 | -0.70 | 0.4900 |
| 8 | 27.08 | 26.50 | -0.58 | 0.3364 |
| 9 | 27.44 | 26.50 | 0.94 | 0.8836 |
| 10 | 26.84 | 26.50 | 0.34 | 0.1156 |
| 11 | 26.40 | 26.50 | -0.10 | 0.0100 |
| 12 | 25.82 | 26.50 | -0.68 | 0.4624 |
| 13 | 26.00 | 26.50 | -0.50 | 0.2500 |
| 14 | 26.15 | 26.50 | -0.35 | 0.1225 |
| 15 | 26.97 | 26.50 | 0.47 | 0.2209 |
| 16 | 27.37 | 26.50 | 0.87 | 0.7569 |
| 17 | 25.54 | 26.50 | 0.96 | 0.9216 |
| 18 | 25.97 | 26.50 | -0.53 | 0.2809 |
| 19 | 25.66 | 26.50 | -0.84 | 0.7056 |
| 20 | 27.41 | 26.50 | 0.91 | 0.8281 |
| 21 | 26.93 | 26.50 | 0.43 | 0.1859 |
| 22 | 26.75 | 26.50 | -0.25 | 0.0625 |

| | | | | |
|---|---|---|---|---|
| 23 | 26.72 | 26.50 | 0.22 | 0.0484 |
| 24 | 25.71 | 26.50 | -0.79 | 0.6241 |
| 25 | 26.45 | 26.50 | -0.05 | 0.0025 |
| 26 | 26.64 | 26.50 | 0.14 | 0.0196 |
| 27 | 27.50 | 26.50 | 0.50 | 0.2500 |
| 28 | 26.24 | 26.50 | -0.26 | 0.0676 |
| 29 | 25.98 | 26.50 | -0.52 | 0.2704 |
| 30 | 26.35 | 26.50 | -0.15 | 0.0225 |
| 31 | 26.98 | 26.50 | 0.48 | 0.2304 |
| 32 | 26.86 | 26.50 | 0.36 | 0.1296 |
| 33 | 26.04 | 26.50 | -0.46 | 0.2116 |
| 34 | 25.91 | 26.50 | -0.59 | 0.3481 |
| 35 | 27.39 | 26.50 | 0.89 | 0.7921 |
| | 928.11 | | | 11.6745 |

## 4.2 STANDARD DEVIATION USING ANOVA AT $\alpha_{0.05}$

In the statistical analysis, two major methods of calculating standard deviation are involved; The T- Distribution and the central limit theorem. For this esearch, T- Distribution is applied in which case the research if any other researcher is carrying out the experiment on these, may not have the patient to generate much results as it is applicable in this research. Which means, in a few sample results, the outcome of the standard deviation will not have much significance difference.

In determining this standard deviation using the T- Distribution method, five selected results are picked and the mean determined, $\bar{x}=\frac{\sum x_i}{n}$ , $\sum(x_i - \bar{x})^2$ , $S^2$ also determined. Then $\bar{x} = Z_{0.025}\frac{S}{\sqrt{n}}\sum \mu \leq \bar{x} + Z_{0.025}\frac{S}{\sqrt{n}}$

$$(Z\alpha/_2 = Z_{0.05}/_2 = Z_{0.025}$$

$Z_{0.025} = 1.96\ which\ is\ standard)$ are evaluated as shown below. For T- Distribution, n = 5

(i) For PW/OW at 9:1 mix:

$\bar{x} = \frac{\sum x_i}{n} = \frac{188.89}{5}$ = 37.778→ 37.80 MJ

$\sum(x_i - \bar{x})^2$ = 2.0574

$S^2$ Which is sample variance →

$$S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})2}{n-1}$$

$S^2 = \frac{2.0574}{5-1} = \frac{2.0574}{4}$ = 0.5144

$S = \sqrt{0.5144}$ = 0.71718

$\bar{x} = Z_{0.025}\frac{S}{\sqrt{n}}\sum \mu \leq \bar{x} + Z_{0.025}\frac{S}{\sqrt{n}}$

$$(Z\alpha/_2 = Z_{0.05}/_2 = Z_{0.025}$$

$Z_{0.025} = 1.96\ which\ is\ standard)$

$$Z_{0.025}\frac{S}{\sqrt{n}} = 1.96(0.32) = 0. = 0.63$$

$$Therefore, the\ value\ for\ PW/OW = 37.8 \pm 0.63$$

$Note$: $\sqrt{5} = 2.2361$

(ii) For TLWW/OW at 9:1 mix:

$\bar{x} = \frac{\sum x_i}{n} = \frac{152.89}{5} = 30.578 \rightarrow 30.60$ MJ

$\sum(x_i - \bar{x})^2 = 2.6565$

$$S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})2}{n-1}$$

$S^2 = \frac{2.6565}{5-1} = \frac{2.6565}{4} = 0.6641$

$S = \sqrt{0.6641} = 0.8149$

$\bar{x} = Z_{0.025}\frac{S}{\sqrt{n}}\sum \mu \leq \bar{x} + Z_{0.025}$

$$\frac{S}{\sqrt{n}}Z_{0.025}\frac{S}{\sqrt{n}} = 1.96(0.3645) = 0.71$$

$$Therefore, the\ value\ for\ TLWW/OW = 30.60 \pm 0.71$$

$Note$: $\sqrt{5} = 2.2361$

(iii) For PW/PCW at 9:1 mix:

$\bar{x} = \frac{\sum x_i}{n} = \frac{188.33}{5} = 37.70 \rightarrow 37.70$ MJ

$\sum(x_i - \bar{x})^2 = 0.9742$

$$S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})2}{n-1}$$

$S^2 = \frac{0.9742}{5-1} = \frac{0.9742}{4} = 0.2436$

$S = \sqrt{0.2436} = 0.4935$

$\bar{x} = Z_{0.025}\frac{S}{\sqrt{n}}\sum\mu \leq \bar{x} + Z_{0.025}$

$$\frac{S}{\sqrt{n}}Z_{0.02} \ \frac{S}{\sqrt{n}} = 1.96(0.2207) = 0.43$$

$$Therefore, the\ value\ for\ PW/PCW = 37.70 \pm 0.43$$

$Note: \sqrt{5} = 2.2361$

(iv) For TLWW/PCW at 9:1 mix:

$\bar{x} = \frac{\sum x_i}{n} = \frac{152.43}{5} = 30.48 \rightarrow 30.50$ MJ

$\sum(x_i - \bar{x})^2 = 1.6711$

$$S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})2}{n-1}$$

$S^2 = \frac{1.6711}{5-1} = \frac{1.6711}{4} = 0.417775$

$S = \sqrt{0.41778} = 0.6464$

$\bar{x} = Z_{0.025}\frac{S}{\sqrt{n}}\sum\mu \leq \bar{x} + Z_{0.025}$

$$\frac{S}{\sqrt{n}}Z_{0.025} = 1.96(0.2890) = 0.57$$

$$Therefore, the\ value\ for\ TLWW/PCW = 30.50 \pm 0.57$$

$Note: \sqrt{5} = 2.2361$

(v) For OW/PCW at 9:1 mix:

$\bar{x} = \frac{\sum x_i}{n} = \frac{89.65}{5} = 17.93 \rightarrow 17.90$ MJ

$\sum(x_i - \bar{x})^2 = 2.4069$

$$S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})2}{n-1}$$

$S^2 = \frac{2.4069}{5-1} = \frac{2.4069}{4} = 0.6017$

$S = \sqrt{0.6017} = 0.7757$

$\bar{x} = Z_{0.025} \frac{S}{\sqrt{n}} \sum \mu \leq \bar{x} + Z_{0.025}$

$$\frac{S}{\sqrt{n}} Z_{0.025} = 1.96(0.3469) = 0.68$$

$$Therefore, the\ value\ for\ OW/PCW = 17.90 \pm 0.68$$

$Note: \sqrt{5} = 2.2361$

(vi) For PW/TLWW at 9:1 mix:

$\bar{x} = \frac{\sum x_i}{n} = \frac{195.85}{5} = 39.17 \rightarrow 39.20$ MJ

$\sum(x_i - \bar{x})^2 = 2.5296$

$$S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})2}{n-1}$$

$S^2 = \frac{2.5296}{5-1} = \frac{2.5296}{4} = 0.6324$

$S = \sqrt{0.6324} = 0.7653$

$\bar{x} = Z_{0.025} \frac{S}{\sqrt{n}} \sum \mu \leq \bar{x} + Z_{0.025}$

$$\frac{S}{\sqrt{n}} Z_{0.025} = 1.96(0.3556) = 0.70$$

$$Therefore, the\ value\ for\ PW/TLww = 39.20 \pm 0.70$$

$Note: \sqrt{5} = 2.2361$

(vii) For PW/PCW at 6:4 mix:

$\bar{x} = \frac{\sum x_i}{n} = \frac{153.77}{5} = 30.80 \rightarrow 30.80$ MJ

$\sum(x_i - \bar{x})^2 = 0.2287$

$$S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})2}{n-1}$$

$S^2 = \frac{0.2287}{5-1} = \frac{0.2287}{4} = 0.0572$

$S = \sqrt{0.0572} = 0.23911$

$\bar{x} = Z_{0.025}\frac{S}{\sqrt{n}}\sum\mu \leq \bar{x} + Z_{0.025}$

$$\frac{S}{\sqrt{n}}Z_{0.025} = 1.96(0.10693) = 0.21$$

$$Therefore, the\ value\ for\ PW/PCW = 30.80 \pm 0.21$$

$Note: \sqrt{5} = 2.2361$

(viii) For PW/OW at 6:4 mix:

$\bar{x} = \frac{\sum x_i}{n} = \frac{156.21}{5} = 31.24 \rightarrow 31.20$ MJ

$\sum(x_i - \bar{x})^2 = 1.6583$

$$S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})2}{n-1}$$

$S^2 = \frac{1.6583}{5-1} = \frac{1.6583}{4} = 0.4146$

$S = \sqrt{0.4146} = 0.6439$

$\bar{x} = Z_{0.025}\frac{S}{\sqrt{n}}\sum\mu \leq \bar{x} + Z_{0.025}$

$$\frac{S}{\sqrt{n}}Z_{0.025} = 1.96(0.2879) = 0.56$$

$$Therefore, the\ value\ for\ PW/OW = 31.20 \pm 0.56$$

$Note: \sqrt{5} = 2.2361$

(ix) For PW/TLWW at 6:4 mix:

$\bar{x} = \frac{\sum x_i}{n} = \frac{183.94}{5} = 36.79 \rightarrow 36.80$ MJ

$\sum(x_i - \bar{x})^2 = 3.4238$

$$S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})2}{n-1}$$

$S^2 = \frac{3.4238}{5-1} = \frac{3.4238}{4} = 0.8559$

$S = \sqrt{0.8559} = 0.9252$

$\bar{x} = Z_{0.025} \frac{S}{\sqrt{n}} \sum \mu \leq \bar{x} + Z_{0.025}$

$$\frac{S}{\sqrt{n}} Z_{0.025} = 1.96(0.4137) = 0.81$$

$$Therefore, the\ value\ for\ PW/TLWW = 36.80 \pm 0.81$$

$Note$: $\sqrt{5} = 2.2361$

(x) For TLWW/OW at 6:4 mix:

$\bar{x} = \frac{\sum x_i}{n} = \frac{131.87}{5} = 26.37 \rightarrow 26.4$ MJ

$\sum(x_i - \bar{x})^2 = 1.0749$

$$S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})2}{n-1}$$

$S^2 = \frac{`.0749}{5-1} = \frac{1.0749}{4} = 0.2687$

$S = \sqrt{0.2687} = 0.5184$

$\bar{x} = Z_{0.025} \frac{S}{\sqrt{n}} \sum \mu \leq \bar{x} + Z_{0.025}$

$$\frac{S}{\sqrt{n}} Z_{0.025} = 1.96(0.2318) = 0.45$$

$$Therefore, the\ value\ for\ TLWW/OW = 26.40 \pm 0.45$$

$Note$: $\sqrt{5}$ = 2.2361

(xi) For TLWW/PCW at 6:4 mix:

$\bar{x} = \frac{\sum x_i}{n} = \frac{129.86}{5}$ = 26.97→ 26.00 MJ

$\sum(x_i - \bar{x})^2$ = 1.0142

$$S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})}{n-1}$$

$S^2 = \frac{1.0142}{5-1} = \frac{1.0142}{4}$ = 0.2534

$S = \sqrt{0.2534.}$ = 0.5035

$\bar{x} = Z_{0.025}\frac{S}{\sqrt{n}}\sum \mu \leq \bar{x} + Z_{0.025}$

$$\frac{S}{\sqrt{n}}Z_{0.025} = 1.96(0.2252) = 0.44$$

$$Therefore, the\ value\ for\ TLWW/PCW = 26.00 \pm 0.44$$

$Note$: $\sqrt{5}$ = 2.2361

(xii) For O/PCW at 6:4 mix:

$\bar{x} = \frac{\sum x_i}{n} = \frac{88.01}{5}$ = 17.60→ 17.60 MJ

$\sum(x_i - \bar{x})^2$ = 0.8974

$$S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})2}{n-1}$$

$S^2 = \frac{0.8974}{5-1} = \frac{0.8974}{4}$ = 0.2244

$S = \sqrt{0.2244}$ = 0.4736

$\bar{x} = Z_{0.025}\frac{S}{\sqrt{n}}\sum \mu \leq \bar{x} + Z_{0.025}$

$$\frac{S}{\sqrt{n}}Z_{0.025} = 1.96(0.2118) = 0.42$$

$$Therefore, the\ value\ for\ OW/PCW = 17.60 \pm 0.42$$

$Note$: $\sqrt{5}$ = 2.2361

(xiii) For PW/TLWW/OW at 5:4:1 mix:

$\bar{x} = \frac{\sum x_i}{n} = \frac{173.12}{5}$ = 34.62→ 34.60 MJ

$\sum(x_i - \bar{x})^2$ = 1.5146

$$S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})2}{n-1}$$

$S^2 = \frac{1.5146}{5-1} = \frac{1.5146}{4}$ = 0.3787

$S = \sqrt{0.3787}$ = 0.6153

$\bar{x} = Z_{0.025}\frac{S}{\sqrt{n}}\sum\mu \leq \bar{x} + Z_{0.025}$

$$\frac{S}{\sqrt{n}}Z_{0.025} = 1.96(0.2751) = 0.54$$

$$Therefore, the\ value\ for\ PW/TLWW/OW = 34.60 \pm 0.54$$

$Note$: $\sqrt{5}$ = 2.2361

(xiv) For PW/TLWW/PCW at 5:4:1 mix:

$\bar{x} = \frac{\sum x_i}{n} = \frac{172.72}{5}$ = 34.54→ 34.50 MJ

$\sum(x_i - \bar{x})^2$ = 1.4442

$$S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})2}{n-1}$$

$S^2 = \frac{1.4442}{5-1} = \frac{1.4442}{4}$ = 0.3611

$S = \sqrt{0.3611}$ = 0.60087

$\bar{x} = Z_{0.025}\frac{S}{\sqrt{n}}\sum\mu \leq \bar{x} + Z_{0.025}$

$$\frac{S}{\sqrt{n}}Z_{0.025} = 1.96(0.2118) = 0.53$$

$$Therefore, the\ value\ for\ PW/TLWW/PCW = 34.50 \pm 0.53$$

$Note$: $\sqrt{5}$ = 2.2361

(xv) For PW/OW/PCW at 5:4:1 mix:

$\bar{x} = \frac{\sum x_i}{n} = \frac{144.38}{5}$ = 28.88→ 28.90 MJ

$\sum(x_i - \bar{x})^2$ = 0.6519

$$S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})2}{n-1}$$

$S^2 = \frac{0.6519}{5-1} = \frac{0.6519}{4}$ = 0.1629

$S = \sqrt{0.1629}$ = 0.4037

$\bar{x} = Z_{0.025}\frac{S}{\sqrt{n}}\sum\mu \leq \bar{x} + Z_{0.025}$

$$\frac{S}{\sqrt{n}}Z_{0.025} = 1.96(0.1805) = 0.35$$

$$Therefore, the\ value\ for\ PW/OW/PCW = 28.90 \pm 0.35$$

$Note$: $\sqrt{5}$ = 2.2361

(xvi) For TLWW/OW/PCW at 5:4:1 mix:

$\bar{x} = \frac{\sum x_i}{n} = \frac{124.61}{5}$ = 24.92→ 24.90 MJ

$\sum(x_i - \bar{x})^2$ = 0.5396

$$S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})2}{n-1}$$

$S^2 = \frac{0.5396}{5-1} = \frac{0.5396}{4}$ = 0.1349

$S = \sqrt{0.}1349$ = 0.3673

$\bar{x} = Z_{0.025}\frac{S}{\sqrt{n}}\sum\mu \leq \bar{x} + Z_{0.025}$

$$\frac{S}{\sqrt{n}} Z_{0.025} = 1.96(0.1642) = 0.32$$

$$Therefore, the\ value\ for\ TLWW/OW/PCW = 24.90 \pm 0.32$$

$Note$: $\sqrt{5}$ = 2.2361

(xvii) For PW/TLWW/OW at 4:3:3 mix:

$\bar{x} = \frac{\sum x_i}{n} = \frac{153.49}{5}$ = 30.69→ 31.00 MJ

$\sum(x_i - \bar{x})^2$ = 2.5145

$$S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})2}{n-1}$$

$S^2 = \frac{2.5145}{5-1} = \frac{2.5145}{4}$ = 0.6286

$S = \sqrt{0.6286}$ = 0.7929

$\bar{x} = Z_{0.025} \frac{S}{\sqrt{n}} \sum \mu \leq \bar{x} + Z_{0.025}$

$$\frac{S}{\sqrt{n}} Z_{0.025} = 1.96(0.3546) = 0.69$$

$$Therefore, the\ value\ for\ PW/TLWW/OW = 31.00 \pm 0.69$$

$Note$: $\sqrt{5}$ = 2.2361

(xviii) For PWTLWW/PCW at 4:3:3 mix:

$\bar{x} = \frac{\sum x_i}{n} = \frac{132.68}{5}$ = 26.53→ 26.50 MJ

$\sum(x_i - \bar{x})^2$ = 1.6098

$$S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})2}{n-1}$$

$S^2 = \frac{1.6098}{5-1} = \frac{1.6098}{4}$ = 0.4025

$S = \sqrt{0.4025}$ = 0.6343

$\bar{x} = Z_{0.025} \frac{S}{\sqrt{n}} \sum \mu \leq \bar{x} + Z_{0.025}$

$$\frac{S}{\sqrt{n}} Z_{0.025} = 1.96(0.2834) = 0.55$$

$$Therefore, the\ value\ for\ PW/TLWW/PCW = 26.5 \pm 0.55$$

$Note$: $\sqrt{5}$ = 2.2361

(xix) For PW/OW/PCW at 4:3:3 mix:

$\bar{x} = \frac{\sum x_i}{n} = \frac{132.67}{5}$ = 26.53→ 26.50 MJ

$\sum(x_i - \bar{x})^2$ = 1.1125

$$S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})}{n-1}$$

$S^2 = \frac{1.1125}{5-1} = \frac{1.1125}{4}$ = 0.2780

$S = \sqrt{0.2780}$ = 0.5273

$\bar{x} = Z_{0.025} \frac{S}{\sqrt{n}} \sum \mu \leq \bar{x} + Z_{0.025}$

$$\frac{S}{\sqrt{n}} Z_{0.025} = 1.96(0.2357) = 0.45$$

$$Therefore, the\ value\ for\ PW/OW/PCW = 26.50 \pm 0.45$$

$Note$: $\sqrt{5}$ = 2.2361

(xx) For TLWW/OW/PCW at 4:3:3 mix:

$\bar{x} = \frac{\sum x_i}{n} = \frac{116.66}{5}$ = 23.33→ 23.30 MJ

$\sum(x_i - \bar{x})^2$ = 1.1418

$$S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})2}{n-1}$$

$S^2 = \frac{1.1418}{5-1} = \frac{1.1418}{4}$ = 0.2855

$S = \sqrt{0.2855}$ = 0.5342

$\bar{x} = Z_{0.025} \frac{S}{\sqrt{n}} \sum \mu \leq \bar{x} + Z_{0.025}$

$$\frac{S}{\sqrt{n}} Z_{0.025} = 1.96(0.2388) = 0.46$$

$$Therefore, the\ value\ for\ TLWW/OW/PCW = 23.30 \pm 0.46$$

$Note$: $\sqrt{5} = 2.2361$

Table 4.26 Experimental Results for the prepared ratios for two combinations

| Combinations | 9:1 | 8:2 | 7:3 | 6:4 | 5:5 |
|---|---|---|---|---|---|
| Plastics/Textiles, leather & wood- (PW/TLWW) | 39.20 | 38.40 | 37.60 | 36.80 | 36.00 |
| Paper/Organic- (PW/OW) | 37.80 | 35.60 | 33.40 | 31.20 | 29.00 |
| Plastics/Paper-carton- (PW/PCW | 37.70 | 35.40 | 33.10 | 30.80 | 28.50 |
| Textiles, leather and wood/Organic- (TLWW/OW) | 30.60 | 29.20 | 27.80 | 26.40 | 25.00 |
| Textiles, leather & wood/Paper-carton- TLWW/PCW) | 30.50 | 29.00 | 27.50 | 26.00 | 24.50 |
| Organic/Paper-carton- ( OW/PCW) | 17.90 | 17.80 | 17.70 | 17.60 | 17.50 |

Table 4.27 Experimental Results for the prepared ratios for three combinations

| Combinations | 5:4:1 | 5:3:2 | 4:3:3 |
|---|---|---|---|
| Plastics/Textiles, wood & leather/Organic | 34.60 | 33.20 | 31.00 |
| Plastics/Textiles, wood &leather/Paper-carton | 34.50 | 28.80 | 26.50 |
| Plastics/organic/Paper-carton | 28.90 | 28.80 | 26.50 |
| Textiles/wood & leather/organic/paper-carton | 24.90 | 24.80 | 23.30 |

Plate 4.1: Municipal Solid Waste Power Plant


Plate 4.2 Refuse selected for the incineration process

Plate 4.3 Refuse separation Process


Plate 4.4  Paper-carton waste selected for Incineration

Plate 4.5 Textiles, leather, wood and plastics waste selected for incineration

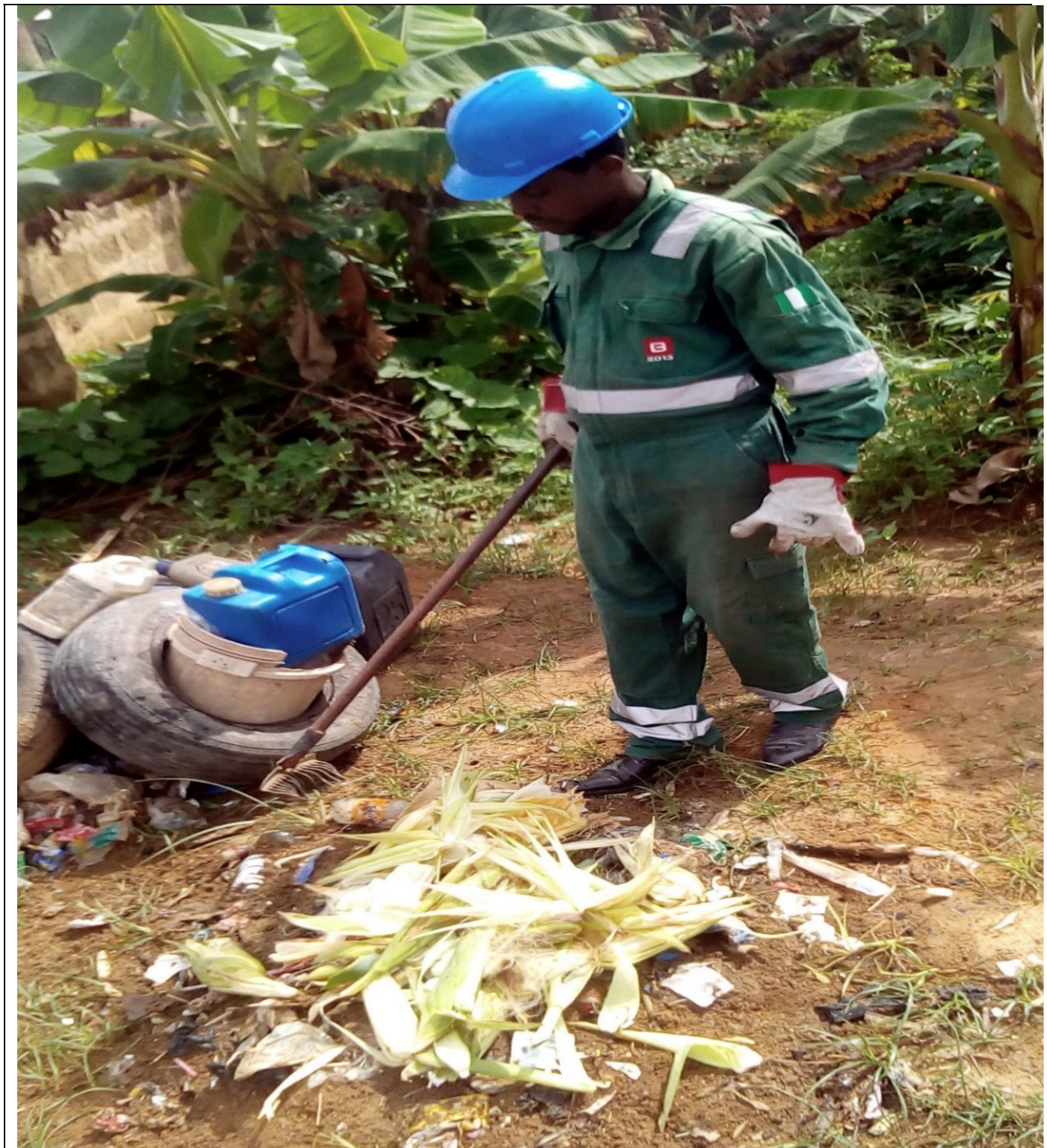

Plate 4.6 Some organic refuse selected for incineration

Plate 4.7 Showing some stages of incineration

Plate 4.8 Setting fire on the waste in the incinerator

Table 4.28: Data Generated from the Incineration Process

| Municipal solid waste mix | Optimum time (hr) | Qty of mix (kg) | Mix ratio | Water level in boiler(litres) | Vapour gas pressure (bar) | Air-fuel ratio | Power Output (Wh) |
|---|---|---|---|---|---|---|---|
| P/TWL | 1:10 | 50 | 9:1 | 40 | 1.40 | 1:4 | 313.00 |
| P/TWL | 1:17 | 50 | 8:2 | 40 | 1.39 | 1:4 | 311.58 |
| P/TWL | 1:24 | 50 | 7:3 | 40 | 1.26 | 1:4 | 309.12 |
| P/TWL | 1:15 | 50 | 6:4 | 40 | 1.21 | 1:4 | 298.50 |
| P/TWL | 1:10 | 50 | 5:5 | 40 | 1.05 | 1:4 | 160.40 |
| P/TWL/O | 1:40 | 50 | 5:4:1 | 40 | 1.00 | 1:4 | 146.16 |
| P/TWL/O | 1:44 | 50 | 5:3:2 | 40 | 1.00 | 1:4 | 146.10 |
| P/TWL/O | 1:43 | 50 | 4:3:3 | 40 | 0.96 | 1:4 | 142.17 |

## 4.4 CALCULATION OF ELECTRICITY POTENTIAL OF MSW IN UYO METROPOLIS

SUMMED PRODUCT OF THE CALORIFIC VALUE

(i) Organic component: $^{66.30}/_{100}$ X 17.60 = 11.93

(ii) Paper-Carton: $^{18.40}/_{100}$ X 17.00= 3.13

(iii) Glass: $^{1.30}/_{100}$ X 0.00 = 0.00

(iv) Plastics: $^{5.20}/_{100}$ X 40.00= 2.08

(v) Iron and Metal Packaging: $^{2.10}/_{100}$ X 0.00 = 0.00

(vi) Textiles, wood, Leather and Elastics: $^{4.30}/_{100}$ X 32.00 = 1.38

(vii) Inert Matter: $^{0.50}/_{100}$ X 0.00 = 0.00

(viii) Others: $^{1.90}/_{100}$ X18.00=0.34

Total 18.86

Table 4.29 Summed product of the calorific values

| S/N | Component | % per Kg- (A) | Caloric Value (MJ/Kg)- (B) | (A) X (B) |
|---|---|---|---|---|
| 1 | Organic | 66.30 | 18.00 | 11.93 |
| 2 | Paper-Carton | 18.40 | 17.00 | 3.13 |
| 3 | Glass | 1.30 | 0.00 | 0.00 |
| 4 | Plastics | 5.20 | 40.00 | 2.08 |
| 5 | Iron and metal packaging | 2.10 | 0.00 | 0.00 |
| 6 | Textiles, Wood, Leather and Elastics | 4.30 | 32.00 | 1.38 |
| 7 | Inert matter | 0.50 | 0.00 | 0.00 |
| 8 | Others | 1.90 | 18.00 | 0.34 |

The calorific value of MSWmunicipal solid waste in Uyo metropolis is given by;
The summed product of the CV (**MJ/Kg**) of dry matter multiplied by the component of the MSW divided by the number of components that possess calorific value.
Therefore, Let **A**= Components in the MSW.
**B**= Calorific value in (MJ/Kg) of dry matter
**C**= Components with calorific value=**5**
The summed product of the calorific value (MJ/Kg) of dry matter= $\sum(A)X(B)$=18.86

$\sum(A)X(B)$/C = 18.86/5 = 3.772 = 3.77MJ/Kg

This value is multiplied by 1000 in order to have the MJ/Ton equivalent and then transformed to KWh/ton = 3772.00 MJ/ton.
Therefore, average CV of MSW generated in Uyo in KWh/ton = (Average calorific value of municipal solid waste (MJ/ton)/3600 X 1000.

=3772/3600 X 1000 =1047.78KWh/ton.

Average CV of MSW generated in Uyo in KWh/ton = 1047.78Kwh/ton.
If we take the conventional thermal efficiency of 40%. The specific power output per ton of waste (Kwh/ton) occurs by multiplying the average calorific value by 0.40 = 419.112Kwh/ton.

Table 4.30 Average calorific value of total waste

| | |
|---|---|
| Average CV of MSW generated in Uyo ( | 1047.78(Kwh/ton) |

Table 4.31 Specific energy output per ton of waste

| | |
|---|---|
| Specific energy content in each tonne of MSW in Uyo | 419.112(Kwh/ton) |

The electricity potential for municipal solid waste mass combustion plant is mathematically deduced thus;

Electricity potential (MW) = (MSW generation X Specific energy content in each tonne of MSW) / Average calorific value of waste)/ 1000

= (72 x419.112)/3.772 ÷1000 = 8.0 MW

The value gives an indication of the maximum capacity level at which a municipal solid waste plant could be developed taking into consideration a 100% mass burning utilization of municipal solid waste produced in Uyo.

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Table 4.32 Table showing the load factor and average KJ/kg of MSW

| Maximum Operating Capacity (KW) | Load Factor (%) | KJ/hr | Average KJ/Kg of MSW |
|---|---|---|---|
| 8000 | 54 | 15551356.04 | 1891.263 |
| 8000 | 53 | 15263367.96 | 1891.263 |
| 8000 | 52 | 14975379.89 | 1891.263 |
| 8000 | 51 | 14687391.82 | 1891.263 |
| 8000 | 50 | 14399403.74 | 1891.263 |
| 8000 | 49 | 14111415.67 | 1891.263 |
| 8000 | 48 | 13823427.59 | 1891.263 |
| 8000 | 47 | 13535439.52 | 1891.263 |
| 8000 | 46 | 13247451.44 | 1891.263 |
| 8000 | 45 | 12959463.37 | 1891.263 |
| 8000 | 44 | 12671475.29 | 1891.263 |
| 8000 | 43 | 12383487.22 | 1891.263 |
| 8000 | 42 | 12095499.14 | 1891.263 |
| 8000 | 41 | 11807511.07 | 1891.263 |
| 8000 | 40 | 11519522.99 | 1891.263 |
| 8000 | 39 | 11231534.92 | 1891.263 |
| 8000 | 38 | 10943546.84 | 1891.263 |
| 8000 | 37 | 10655558.74 | 1891.263 |
| 8000 | 36 | 10367570.69 | 1891.263 |
| 8000 | 35 | 10079582.62 | 1891.263 |
| 8000 | 34 | 9791594.54 | 1891.263 |

Table 4.33: Showing load factor and quantity of MSW in combustor per day

| Maximum Operating Capacity (KW) | Load Factor (%) | Qty of MSW in Combustor (Kg/hr | Qty of MSW in Combustor (Tonnes/day) |
|---|---|---|---|
| 8000 | 54 | 8229.196 | 197.501 |
| 8000 | 53 | 8076.804 | 193.843 |
| 8000 | 52 | 7924.411 | 190.186 |
| 8000 | 51 | 7772.019 | 183.528 |
| 8000 | 50 | 7619.626 | 182.871 |
| 8000 | 49 | 7469.234 | 179.241 |
| 8000 | 48 | 7314.841 | 175.556 |
| 8000 | 47 | 7162.449 | 171.899 |
| 8000 | 46 | 7010.056 | 168.241 |
| 8000 | 45 | 6857.664 | 164.582 |
| 8000 | 44 | 6705.271 | 160.927 |
| 8000 | 43 | 6552.878 | 157.269 |
| 8000 | 42 | 6400.486 | 153.612 |
| 8000 | 41 | 6248.093 | 149.954 |
| 8000 | 40 | 6095.701 | 146.297 |
| 8000 | 39 | 5943.308 | 142.639 |
| 8000 | 38 | 5790.916 | 138.982 |
| 8000 | 37 | 5638.523 | 135.325 |
| 8000 | 36 | 5486.131 | 131.667 |
| 8000 | 35 | 5333.738 | 128.009 |
| 8000 | 34 | 5181.346 | 124.352 |

Table 4.34 Showing load factor and heat rate

| Maximum Operating Capacity (KW) | Load Factor (%) | Qty of MSW in Combustor (Tonnes/year) | Heat Rate |
|---|---|---|---|
| 8000 | 54 | 72087.865 | 3603 |
| 8000 | 53 | 70752.801 | 3603 |
| 8000 | 52 | 69417.842 | 3603 |
| 8000 | 51 | 68082.883 | 3603 |
| 8000 | 50 | 66747.925 | 3603 |
| 8000 | 49 | 65412.966 | 3603 |
| 8000 | 48 | 64078.008 | 3603 |
| 8000 | 47 | 62743.049 | 3603 |
| 8000 | 46 | 61408.091 | 3603 |
| 8000 | 45 | 60073.132 | 3603 |
| 8000 | 44 | 58738.174 | 3603 |
| 8000 | 43 | 57403.215 | 3603 |
| 8000 | 42 | 56068.257 | 3603 |
| 8000 | 41 | 54733.298 | 3603 |
| 8000 | 40 | 53398.340 | 3603 |
| 8000 | 39 | 52063.381 | 3603 |
| 8000 | 38 | 50728.423 | 3603 |
| 8000 | 37 | 49393.464 | 3603 |
| 8000 | 36 | 48058.502 | 3603 |
| 8000 | 35 | 46723.547 | 3603 |
| 8000 | 34 | 45388.589 | 3603 |

Table 4.35 Table showing load factor and KWh annual production

| Maximum Operating Capacity (KW) | Load Factor (%) | Average KJ/Kg of MSW | KWh Annual Production |
|---|---|---|---|
| 8000 | 54 | 1891.263 | 37843200 |
| 8000 | 53 | 1891.263 | 37142400 |
| 8000 | 52 | 1891.263 | 36441600 |
| 8000 | 51 | 1891.263 | 35740800 |
| 8000 | 50 | 1891.263 | 35040000 |
| 8000 | 49 | 1891.263 | 34339200 |
| 8000 | 48 | 1891.263 | 33638400 |
| 8000 | 47 | 1891.263 | 32937600 |
| 8000 | 46 | 1891.263 | 32236800 |
| 8000 | 45 | 1891.263 | 31536000 |
| 8000 | 44 | 1891.263 | 30835200 |
| 8000 | 43 | 1891.263 | 30134400 |
| 8000 | 42 | 1891.263 | 29433600 |
| 8000 | 41 | 1891.263 | 28732800 |
| 8000 | 40 | 1891.263 | 28032000 |
| 8000 | 39 | 1891.263 | 27331200 |
| 8000 | 38 | 1891.263 | 26630400 |
| 8000 | 37 | 1891.263 | 25929600 |
| 8000 | 36 | 1891.263 | 25228800 |
| 8000 | 35 | 1891.263 | 24528000 |
| 8000 | 34 | 1891.263 | 23827200 |

**Summary of the equations**

Quantity of MSW in combustor (Kg/hr)=(KJ/hr)/Average KJ/kg of MSW

Quantity of MSW in Combustor (Tonnes/day)=Qty of MSW (kg/hr)X24/1000

Quantity of MSW in combustor (Tonnes/year)=MSW (Tonnes/day)X365

KWh Annual production=Maximum capacity load factor X 24 X 365

Heat rate= (KJ/hr) X 24 X 365/KWh Annual Production

Total quantity of municipal solid waste generated in Uyo/day = **200,000 Kg/day**

Average calorific value of waste generated in Uyo=**1047.78Kwh/ton=3772kj/kg**

Optimal Operating capacity = **8000KW=8MW**

Actual Operating Capacity Ranges from **3.4⇒5.4MW**. For this research,the load factor is at **4.4MW.** This is due to plant's capacity level according to Ikywashima company ltd of Japan.

44% load factor, the quantity of municipal solid waste per hour at this load factor that goes into the combustor per hour =**6705.271Kg/hr.**

Energy output from the combustor (Incinerator) to the boiler (steam generator) at 44% load factor =**12663 Mj/hr**

Specific energy output per tonne of waste =**384.686 KWh/ton= 1320.228Kj/kg.**

The temperature of the superheated steam =**300 $^{o}$C**.

The pressure of the superheated steam =**25 bar**

Exhaust pressure=(back pressure) = **10 bar**

Table 4.36 Showing thermodynamic properties of the plant

| Parameter | Symbol | Unit | Value | Parameter | Symbol | Unit | Value |
|---|---|---|---|---|---|---|---|
| Specific volume(Sat.liquid) | $V_f$ | $m^3/kg$ | 0.0014 | Specific Volume(Sat.vapour) | $V_g$ | $m^3/kg$ | 0.02167 |
| Internal Energy(Sat.liquid) | $U_f$ | $kj/kg$ | 1320.0 | Internal Energy(Evap.steam) | $U_{fg}$ | $kj/kg$ | 1231.0 |
| Internal energy(Sat.vapour) | $U_g$ | $kj/kg$ | 2563.0 | Enthalpy(Sat.liquid | $h_f$ | $kj/kg$ | 1344.0 |
| Enthalpy of Evaporation | $h_{fg}$ | $kj/kg$ | 1404.9 | Enthalpy(Sat.vap.) | $h_g$ | $kj/kg$ | 2749.0 |
| Enthropy(Sat.liquid | $S_f$ | $\frac{Kj}{kg} - K$ | 3.2534 | Enthropy of Evaporation | $S_{fg}$ | $\frac{Kj}{kg} - K$ | 2.4511 |
| Entropy( sat.vapour) | $S_g$ | $\frac{Kj}{kg} - K$ | 5.7045 | | | | |

According to Ikiwashima Company Ltd of India, the load factor for this plant is within the range of 3.4 to 5.4 (i.e 34 to 54%). 44% is the range value within this range. At this load factor, the amount of MSW in the combustor, KJ/hr is given as 6705.271 and the energy output from the combustor at this load factor is given as 12663Mj/hr which is going into the boiler.

Since the total MSW generated in Uyo metropolis is 200 tonnes each day which is equivalent to 200000 kg/day and that which goes into the combustor (Incinerator) every hour is 6.705 tonnes. Dividing the 200000 kg of MSW generated in Uyo daily by the quantity of MSW that goes into the combustor gives 29.85hrs of operation. This shows that the plant can run conveniently throughout the day without any issue of lack of fuel (municipal solid waste). From the analysis, quantity of heat that goes into the turbine is 2.01Kwh at 300$^{o}$C.

The final power output from the turbine will be equal to generator kwh/generator efficiency. This is equivalent to 2.01/0.44=4.56kwh.

This value is equivalent to 16416KJ or 16.416mj. This value gives daily power production of 109.44kwh and the annual plant efficiency is 109.4x 365days which is 39945kwh.

At the same time, the average quantity in megawatt of electricity from the national grid to Uyo used to be 50 MW per month initially. Presently the State government (AkwaIbom State) has been disconnected from the national grid due to the commissioning of Ibom power plant (IPP) in IkotAbasi local L.G.A of the state. Presently, the plant is producing about 100MW from its gas station. The state has three sub-stations, namely Itu, Eket and Uyo and the 100 Mw is divided for the three sub stations. Uyo being the state capital with higher load takes about 40 % amounting to 40 Mw. The Uyo district comprise of about 10 local government area. Uyo metropolis alone takes about 10 Mw of the electricity. As such the plant in research will be able to serve the whole of Nwaniba (University of Uyo permanent site) which the entire University consume about 3Mw and the densely populated area of Oron road in Uyo.

## 4.5 ECONOMICS

The aim of the economic assessment is to establish whether or not the development of a 8 MW MSW combustion plant for an area of Uyo metropolis would be a profitable investment or not . If there will be any economic benefit taking into consideration all other environmental factors.

Table 4.37 Capital Cost of 8 MW MSW Combustion System.

| Capital Costs. | ₦ | % |
|---|---|---|
| MSW handling, storage and processing | 21,600,000.00 | |
| Rolling grate incinerator | 23,800,000.00 | |
| Steam boiler and feed heating system | 28,000,000.00 | |
| Steam-gas Turbine System | 145,000,000.00 | |
| Stack gas clean up and pollution control | 28,000,000.00 | |
| Field purchase and construction | 25,000,000.00 | |
| Plant engineering | 23,600,000.00 | |
| TOTAL | 295,000,000.00 | |

Table 4.38 Labour Wages per shift for one year

| Occupation | Number of Employees per Shift | Labour Wages (₦/year) |
|---|---|---|
| Workers | 13 | 9, 800, 035.88 |
| Engineers | 5 | 12, 224, 000.00 |
| Shift Managers | 3 | 7, 916, 002.88 |
| General Manager | 1 | 3, 593, 294.57 |
| TOTAL | 30 | 33, 533, 333.33 |

Table 4.39 Labour Wages for Three Shift per year

| Occupation | Number of Employees | Labour Wages (₦/year) |
|---|---|---|
| Workers | 39 | 29, 400, 107.64 |
| Engineers | 15 | 36, 672, 000.00 |
| Shift Managers | 9 | 23, 748, 008.64 |
| General Managers | 3 | 10, 779, 883.71 |
| TOTAL | 90 | 100, 600, 000.00 |

Table 4.40 Annual Operating Cost of 8 MW MSW Combustion Plant

| Annual Operating Cost. | ₦. | %. |
|---|---|---|
| Total yearly Usage and Maintenance Cost (O & M) | 44, 218, 132.31 | 20.5 |
| Capital Charge Rate | 69, 886, 218.87 | 32.4 |
| Total Labour Cost | 82, 620, 126.36 | 38.30 |
| Plant Insurance | 1, 898, 144.22 | 8.8 |
| TOTAL | 198, 622, 621.80 | 100 |

Therefore, total cash outflows for the period (n) of one year

Capital cost of 8 MW plant + Labour cost for one year + Annual operating cost of the plant =

295, 000, 000.00
100, 600, 000.80
+ 198, 622, 621.80
₦ 594, 222, 622.60

Cash inflow from the 8 MW MSW combustion plant is given by the total sales of the electricity that is generated.

Total annual power production is given by 30835200kwh.

Current charge of electricity for residential area of Uyo(current NEPA bill in Uyo, 2016) = ₦ 12.82/KWh

Therefore, annual sales is given by 30835200 * 18.47 = ₦ 395, 307, 264.00

Annual Cashflow = Total sales – ( Labour cost + Operating Cost)

= 395, 307, 246.00 – (100, 600, 000.00+ 198, 622, 621.80). All in (₦)

= ₦96, 084, 642.00

**PAYBACK PERIOD**

This measures the number of years it takes this project to recoup its initial investment, given its annual cashflows. Which is given by; $PbP = \frac{Initial\ outlay}{Annual\ Cashflow} = \frac{295{,}000{,}000}{96{,}084{,}642.00}$

= 3.07 years.

This value shows actual payback period of the project.

**NET PRESENT VALUE**

NPV measures the amount of currency presently with the amount of same denomination tomorrow considering the increase account and return. If NPV of a prospective business is positive, then it can result to be economically viable, but if minus, then involving in the project should be declined.

From the explanation, the NPV is as follows;

$$\mathrm{NPV} = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n} = 0$$

Denoting $n$ as positive integer.

Total periods as $N$, and $\mathrm{NPV}$ which is to be calculated.
Numerical equation to calculate $r$. ant method]], $r$ is can be written as

$$r_{n+1} = r_n - \mathrm{NPV}_n \left( \frac{r_n - r_{n-1}}{\mathrm{NPV}_n - \mathrm{NPV}_{n-1}} \right).$$

where $r_n$ is considered the $n^{\text{th}}$ approximation of the IRR

Now, Substituting the value in the equations, gives

Cn=Cash flows

N= The total amount of time which is the period

NPV= Net Present Value

r =IRR

Discount factor = $\frac{1}{(1+r)^n}$

Where r = Interest rate

n= Period (in years,0, 1, 2, 3,--------,nth year)

Taking interest rate **@ 15%**

Calculation of the discount factors;

For year 0; $\frac{1}{(1+r)^n} = \frac{1}{(1+0.15)^0} = \frac{1}{(1.15)^0}$ = 1.000

For year 1; $\frac{1}{(1+r)^n} = \frac{1}{(1+0.15)^1} = \frac{1}{(1.15)^1}$ = 0.8696

For year 2; $\frac{1}{(1+r)^n} = \frac{1}{(1+0.15)^2} = \frac{1}{(1.15)^2}$ = 0.7561

For year 3; $\frac{1}{(1+r)^n} = \frac{1}{(1+0.15)^3} = \frac{1}{(1.15)^3}$ = 0.6575

For year 4; $\frac{1}{(1+r)^n} = \frac{1}{(1+0.15)^4} = \frac{1}{(1.15)^4}$ = 0.5718

For year 5; $\frac{1}{(1+r)^n} = \frac{1}{(1+0.15)^5} = \frac{1}{(1.15)^5}$ = 0.4972

Table 4.41: Cash Flow Analysis

| Year | Cashflow (₦) | Discount factor | Pv (₦) |
|---|---|---|---|
| 0 | 295, 000, 000.00 | 1.0000 | (295, 000, 000.00) |
| 1 | 96, 084, 642.20 | 0.8696 | 83, 551, 862.78 |
| 2 | 96, 084, 642.20 | 0.7561 | 72, 653, 793.72 |
| 3 | 96, 084, 642.20 | 0.6575 | 63, 180, 327.59 |
| 4 | 96, 084, 642.20 | 0.5718 | 54 ,936, 902.34 |
| 5 | 96, 084, 642.20 | 0.4972 | 47, 770, 031.92 |
| NPV | | | (27,092, 918.35) |

Taking interest rate @ 30%

Calculation of the discount factors;

For year 0; $\frac{1}{(1+r)^n} = \frac{1}{(1+0.3)^0} = \frac{1}{(1.3)^0} = 1.000$

For year 1; $\frac{1}{(1+r)^n} = \frac{1}{(1+0.3)^1} = \frac{1}{(1.3)^1} = 0.7692$

For year 2; $\frac{1}{(1+r)^n} = \frac{1}{(1+0.3)^2} = \frac{1}{(1.3)^2} = 0.5917$

For year 3; $\frac{1}{(1+r)^n} = \frac{1}{(1+0.3)^3} = \frac{1}{(1.3)^3} = 0.4552$

For year 4; $\frac{1}{(1+r)^n} = \frac{1}{(1+0.3)^4} = \frac{1}{(1.3)^4} = 0.3501$

For year 5; $\frac{1}{(1+r)^n} = \frac{1}{(1+0.3)^5} = \frac{1}{(1.3)^5} = 0.2693$

Table 4.42: Showing Cash Flow

| Year | Cashflow (₦) | Discount factor | Pv (₦) |
|---|---|---|---|
| 0 | 295, 000, 000.00 | 1.0000 | (295, 000, 000.00) |
| 1 | 96, 084, 642.20 | 0.7692 | 73, 908, 306.78 |
| 2 | 96, 084, 642.20 | 0.5917 | 56, 853, 282.79 |
| 3 | 96, 084, 642.20 | 0.4552 | 43, 737, 729.13 |
| 4 | 96, 084, 642.20 | 0.3501 | 33, 639, 233.23 |
| 5 | 96, 084, 642.20 | 0.2693 | 25, 875, 594.14 |
| NPV | | | (60, 985, 853.93) |

Taking interest rate @ 20%

Calculation of the Discount Factor;

For year 0; $\frac{1}{(1+r)^n} = \frac{1}{(1+0.2)^0} = \frac{1}{(1.2)^0}$ = 1.000

For year 1; $\frac{1}{(1+r)^n} = \frac{1}{(1+0.2)^1} = \frac{1}{(1.2)^1}$ =

For year 2; $\frac{1}{(1+r)^n} = \frac{1}{(1+0.2)^2} = \frac{1}{(1.2)^2}$ =

For year 3; $\frac{1}{(1+r)^n} = \frac{1}{(1+0.2)^3} = \frac{1}{(1.2)^3}$ =

For year 4; $\frac{1}{(1+r)^n} = \frac{1}{(1+0.2)^4} = \frac{1}{(1.2)^4}$ =

For year 5; $\frac{1}{(1+r)^n} = \frac{1}{(1+0.2)^5} = \frac{1}{(1.2)^5}$ =

Table 4.43: Showing Cash Flow

| Year | Cashflow (₦) | Discount factor | Pv (₦) |
|---|---|---|---|
| 0 | 295, 000, 000.00 | 1.0000 | (295, 000, 000.00) |
| 1 | 96, 084, 642.20 | | 80, 070, 535.17 |
| 2 | 96, 084, 642.20 | | 66, 725, 445.97 |
| 3 | 96, 084, 642.20 | | 55, 604, 538.31 |
| 4 | 96, 084, 642.20 | | 46, 337,115.26 |
| 5 | 96, 084, 642.20 | | 38, 614, 262.64 |
| NPV | | | (7, 648, 102.66) |

**INTERNAL RATE OF RETURN**

**IRR** = $DL = \left(\frac{NPV_P}{NPV_P + NPV_N}\right) * DH - DL$

Where;DL = Lower discount factor

DH = Higher Discount factor

$NPV_P$ = Positive NPV

$NPV_N$ = Negative NPV

Now taking the Higher discount factor and the lower discount factor to be 30% and 15% respectively, gives internal rate of return as follow;

$$IRR = 0.15 + \left(\frac{27,092,918.35}{27,092{,}918.35 + 60,985,853.93}\right) * 0.3 - 0.15$$

$$= 0.15 + \left(\frac{27,\ 092,\ 918.35}{8,\ 8078,\ 772.28}\right) * 0.15$$

= 0.15 + $(0.3075987284) * 0.15$

= 0. 15 + 0.04619

= 0.196

= 19.6%

Now taking the Higher discount factor and the lower discount factor to be 20% and 15% respectively, gives internal rate of return as follow;

$$IRR = 0.15 + \left(\frac{27,092,918.35}{27,092{,}918.35 + 7648102.66}\right) * 0.2 - 0.15$$

$$= 0.15 + \left(\frac{27,\ 092,\ 918.35}{34741021.01}\right) * 0.05$$

= 0.15 + $(0.7798) * 0.05$

= 0. 15 + 0.03899

= 0.153

= 15.3%

## 4.6 EMISSION ANALYSIS

MSW in this research comprises the following:

- ❖ Organic waste-O
- ❖ Textiles, Wood, Leather- TWL
- ❖ Paper- Carton-PC
- ❖ Plastics-P
- ❖ Metals- M
- ❖ Glass-G
- ❖ Inert Matter-IM
- ❖ Others-OT

**Predominant Emission from Each Relevant Group of Municipal Solid Waste**

- ❖ Organic waste
    - Carbon dioxide
    - Methane
    - Nitrogen dioxide
    - Carbon monoxide
    - Sulphur dioxide
    - Hydrogen bromide
    - Hydrogen chloride
    - Etc.

Note: Total emission counted in units of $CO_2$ equivalent ($CO_2$eq) calculated based on their different global warming greenhouse gas emission potential.

Greenhouse Gas Factors

| | |
|---|---|
| $CO_2$emission | = 1 |
| $CH_4$emission | = 21 |
| $NO_2$NO2 emission | = 310 |

- ❖ Leather waste
    - Nitrogen
    - Phosphorus
    - Chromium

- Sulphur
- Carbon monoxide
- Hydrogen Chloride

❖ Plastic waste

| | |
|---|---|
| • Carbon dioxide | very high |
| • Nitrogen dioxide | relatively high |
| • Hydrogen Chloride | very high |
| • Water vapour | relatively high |
| • Heavy metals | very high |

For example, in the combustion of plastic like Polyvinylchloride (PVC), The following combustion reaction takes place;

PVC + $O_2$= Water vapour+ Carbon dioxide + Carbon + Hydrogen Chloride

So many other type of plastics will have other types of emission and some similar to that of the PVC depending on their production constituents

❖ Wood

- Water vapour
- Carbon dioxide
- Some little quantity of other elements

For instance, in the combustion of wood, the chemical nature of wood is closely related to sugars. To make things easier and simpler, wood is considered to be composed just of sugars, in which the equation is given as $C_6H_{12}O_6$

Therefore, when burning wood, the wood reacts with oxygen in air as follows;

$C_6H_{12}O_6 + 6O_2 = H_2O$

The combustion products are carbon (IV) oxide in addition to vapour. The good aspect of the combustion using wood is that, as carbon dioxide which is a major greenhouse gas is produced, it is simultaneously absorbed by the growing trees in the forest and the environs. It is considered to be carbon neutral.

Data Sourced from Literature search on the Emission of Some Municipal Solid Waste

Table. 4.44 Carbon Content of Different Waste Components

| S/N | Waste Component | Total Carbon (TC) in MSW (% of mass | Degradable Organic Carbon (DOC) in MSW (% of mass) | Dissimilable Organic Carbon (DOCF) in MSW (% of DOC) | Fossil Carbon (FC) in MSW (% of mass) |
|---|---|---|---|---|---|
| 1 | Organic | 19 | 19 | 64 | 0 |
| 2 | Wood | 45 | 30 | 50 | 0 |
| 3 | Textiles | 39 | 20 | 30 | 19 |
| 4 | Paper-Carton | 33 | 33 | 35 | 0 |
| 5 | Plastics | 61 | 0 | 0 | 61 |
| 6 | Metals | 0 | 0 | 0 | 0 |
| 7 | Glass | 0 | 0 | 0 | 0 |
| 8 | Others | 24 | 16 | 39 | 8 |

Source: AEA (2001), Page 97

Table 4.45 Summary of emission Characteristics of Hazardous Waste

| S/N | Combustion Materials | EF [mg/kg] TPM | EF [mg/kg] PM10 | EF [mg/kg] PM2.5 |
|---|---|---|---|---|
| 1 | Paper | 1300 | 930 | 600 |
| 2 | Wood | 1000 | 830 | 500 |
| 3 | Plastics | 1700 | 1500 | 500 |
| 4 | Organic | 1500 | 1200 | 780 |

Source: Aerosol and Air Quality Research

EF= Emission Factor

TPM= Total Particulate Matter

PM10= Particulate Matter measured at 10milligram

PM2.5= Particulate matter measured at 2.5 milligram

Table 4.46 Emission Factors involving high weight elements

| S/N | Element | Paper | Wood | Plastics | Organic | Textiles |
|---|---|---|---|---|---|---|
| 1 | Pb | 0.01-0.07 | 0.05-0.10 | 0.02-1.13 | 0.01-1.13 | 0.01-0.04 |
| 2 | Ni | 0.2-0.26 | 0.07-0.50 | 0.05-0.24 | 0.15-0.66 | 0.04-0.06 |
| 3 | Cu | 0.07-0.22 | 0.05-0.18 | 0.04-0.12 | 0.04-0.08 | 0.03-0.15 |
| 4 | Cd | 0.02-0.05 | 0.01-0.19 | 0.01-0.02 | 0.01-1.12 | 0.01-0.17 |
| 5 | Cr | 0.33-0.38 | 0.14-0.46 | 0.36-1.46 | 0.53-1.02 | 0.12-0.32 |
| 6 | Zn | 0.01-18.19 | 2.69-15.65 | 3.78-65.17 | 13.29-14.16 | 2.21.12.14` |

Source: United State Environmental Protection Agency Emission Inventory Improvement Programme (EC/R, 2002): EIIP, (2004).

Pb = Lead
Ni= Nickel
Cu= Copper
Cd= Cadmium
Cr= Chromium
Zn= Zinc

**Summary**

With reference to Table 4.1, table 4.1 shows that paper, wood, textiles and organic waste have relatively low emission factors of particulate element of lead, nickel, copper, cadmium, chromium and zinc compared to plastics which is relatively very high.

With reference to table 4.2, table 4.2 shows the summary of emission characteristics of hazardous waste of paper, wood, plastics and organic waste with the following parameters: EF= Emission Factor

TPM= Total Particulate particle

PM10= Particulate particle measured at 10milligram

PM2.5= Particulate matter measured at 2.5 milligram

In which the values are given in the table.

The data obtained shows that, paper, wood, and organic have relatively low values compared to plastics which is higher. Meaning it has a more emission compared to others.

With reference to table 4.3, it means that, carbon content from different waste components of organic, wood, textiles, paper-carton, plastics, metals, glass and others. From the search, the total carbon (TC) and the fossil carbon (FC) are the factors that generate emissions during combustion of these waste materials. From the data, organic, wood, textiles, paper-carton and other types of waste have relatively low values compared to plastic waste.

**DEDUCTIONS**

From table 4.6 for model results for the prepared ratios of 9:1 at two combinations of MSW of Plastics- P and Textiles, wood and leather- TWL which produces the calorific value of 39.20MJ. Meaning, 90% of Plastic fuel and 10% of Textiles, wood and leather fuel at a particular time in the combustion chamber. Also, from table 4.6 for the model results for the prepared ratios of 5:4:1 at three combinations of MSW. That of Plastics-P, (Textiles, Wood, Leather)- TWL, and Organic- O which produces the calorific value of 34.6MJ. Meaning that 50% of Plastic fuel, 40% of Textiles, Wood, Leather fuel and 10% of Organic fuel was used at a particular time in the combustion chamber.

With reference to table 4.1, 4.2, 4.3, it is shown that the emission factors of plastic, the carbon content of plastics and the emission characteristics of plastics are always higher than any other type of MSW. By this combination of MSW mix (MSWM), the emission from plastics will be low considering that other types of waste element have lesser values of this parameters and still achieve a better calorific values for energy generation.

# CHAPTER FIVE

## 5.0 CONCLUSION

Waste, at the beginning of this write up has been described as anything in which its usefulness is no longer needed at that particular time and place. It can also be described as something which people don't make use of at that time and the economic use is not appreciable. This discussion makes it easier to know what could be described as waste. Gaseous waste move from one point to the other in the form of osmosis. Solid waste are the waste that flows in the cutters, drains and channels.

In the course of this research, it is established that the thought that what people perceived as waste is not directly waste but "wealth". As these could be converted to different aspects that positively affect the life of human. Presently, it could be converted to generate fossil fuels; municipal solid waste can still be recycled to produce other useful products for man use. Fertilizers, which is used for agricultural activities may be produced from reuse in the form of recycling of refuse. Various forms of fertilizers could be produced from recycled sewage and other domestic refuse and garbage.

This particular study has shown that, it is possible to generate electric power through municipal solid waste (MSW) by incineration process.

The study also identified the objectives to be achieved. These include, firstly, determining the total amount and content of MSW generation in Uyo metropolis. Secondly, classification of MSW composition in Uyo metropolis. Thirdly,energy output from each of the waste composition. Also, energy content coming out of each of the waste constituent. Finally, developing a model to ascertain which of the waste combination will give a better energy output taking into consideration the quantity of municipal solid waste.

It is obvious that these objectives are fully addressed

The theoretical operating capacity of the plant is 8 MW. According to Ikiwashima Company Ltd of India, the load factor for this plant is within the range of 3.4 to 5.4 (i.e

34 to 54%). 44% is the range value within this range. At this load factor, the amount of MSW in the combustor in KJ/hr which is given as 6705.271 and the energy output from the combustor at this load factor is given as 12663Mj/hr which is going into the boiler.

Since the total MSW generated in Uyo metropolis is 200 tonnes/day which is equivalent to 200000 kg/day and that which goes into the combustor (Incinerator) every hour is 6.705 tonnes. Dividing the 200000 kg of municipal solid waste generated in Uyo each day by that quantity of MSW that goes into the combustor gives 29.85hrs of operation. This shows that the plant can run conveniently throughout the day without any issue of lack of fuel (municipal solid waste). From the analysis, quantity of heat that goes into the turbine is 2.01Kwh at 300$^{o}$C.

The final power output from the turbine will be equal to generator kwh/generator efficiency. This is equivalent to 2.01/0.44=4.56kwh.

This value is equivalent to 16416KJ or 16.416mj. This value gives daily power production of 109.44kwh and the annual plant efficiency is 39945kwh.

At the same time, the average quantity in megawatt of electricity from the national grid to Uyo used to be 50 MW per month initially. Presently the State government (AkwaIbom State) has been disconnected from the national grid due to the commissioning of Ibom  power plant (IPP) in IkotAbasi. Presently, the plant is producing about 100 MW from its gas station. The state have three sub stations, namely Itu, Eket and Uyo and the 100 Mw is divided for the three sub stations. Uyo being the state capital with higher load takes about 40 % amounting to 40 Mw. The Uyo district comprise of about 10 local government area. Uyo metropolis alone takes about 10 Mw of the electricity. As such the plant in research will be able to serve the whole of Nwaniba( University of Uyo permanent site)  which the entire University consume about 3Mw and the densely populated area of Oron road in Uyo.

It is obvious from the analysis that this project will remarkably curb to some extent, the poverty level in the society considering the number of people that is going to employ. This will also help the government in cutting down the unemployment level in the society that has been a serious problem to government.

Apart from creating job opportunities to the citizenry, it will also generate income to the system considering the fast payback period, a better economic value to the society. Finally, as it were the practice in a great many developed economies, environmental legislation should appreciate various means of what is expected from corporate organisation and parastatals for environmental protection in investing in MSW. This will go a long way in eliminating most of the waste management issues.

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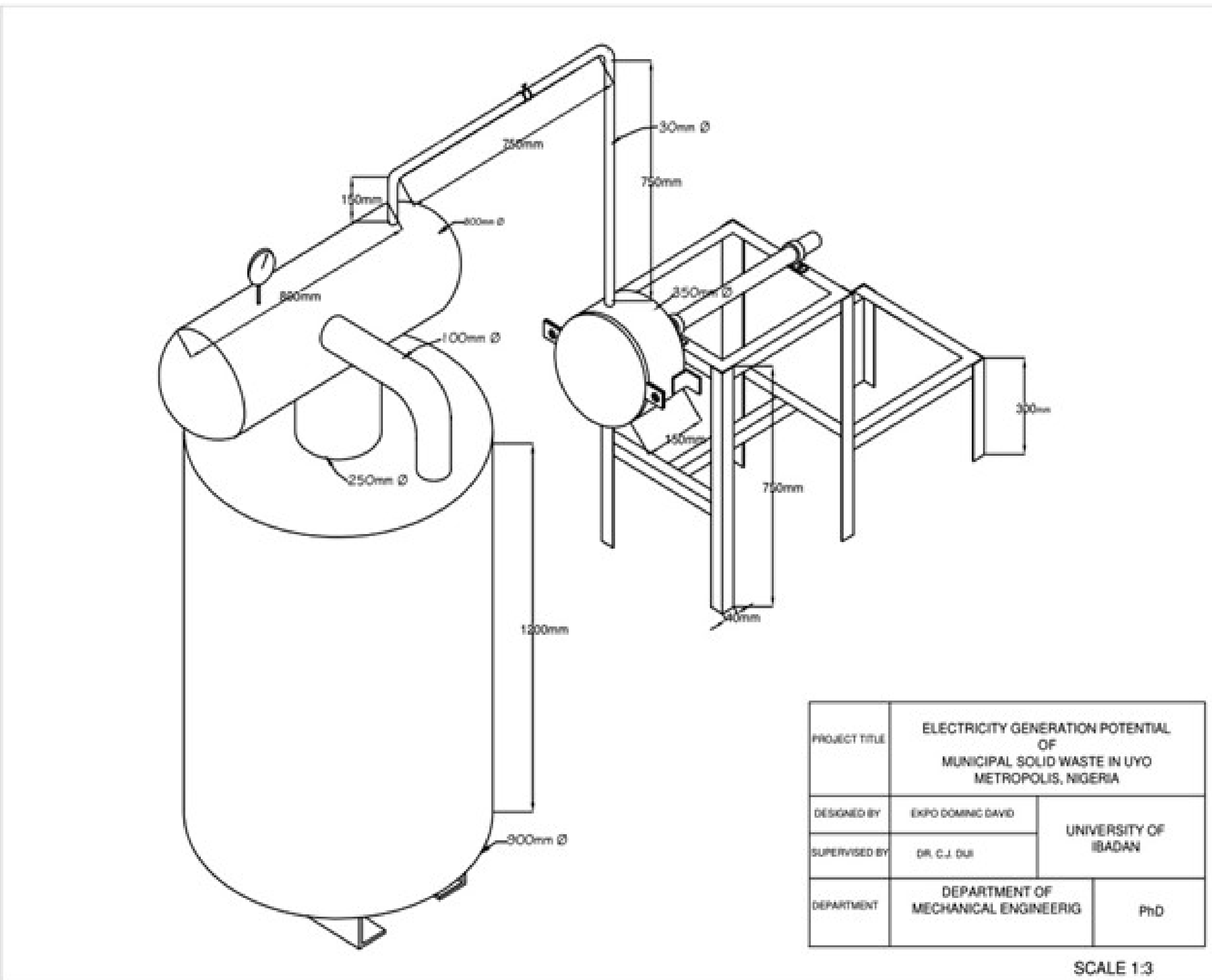
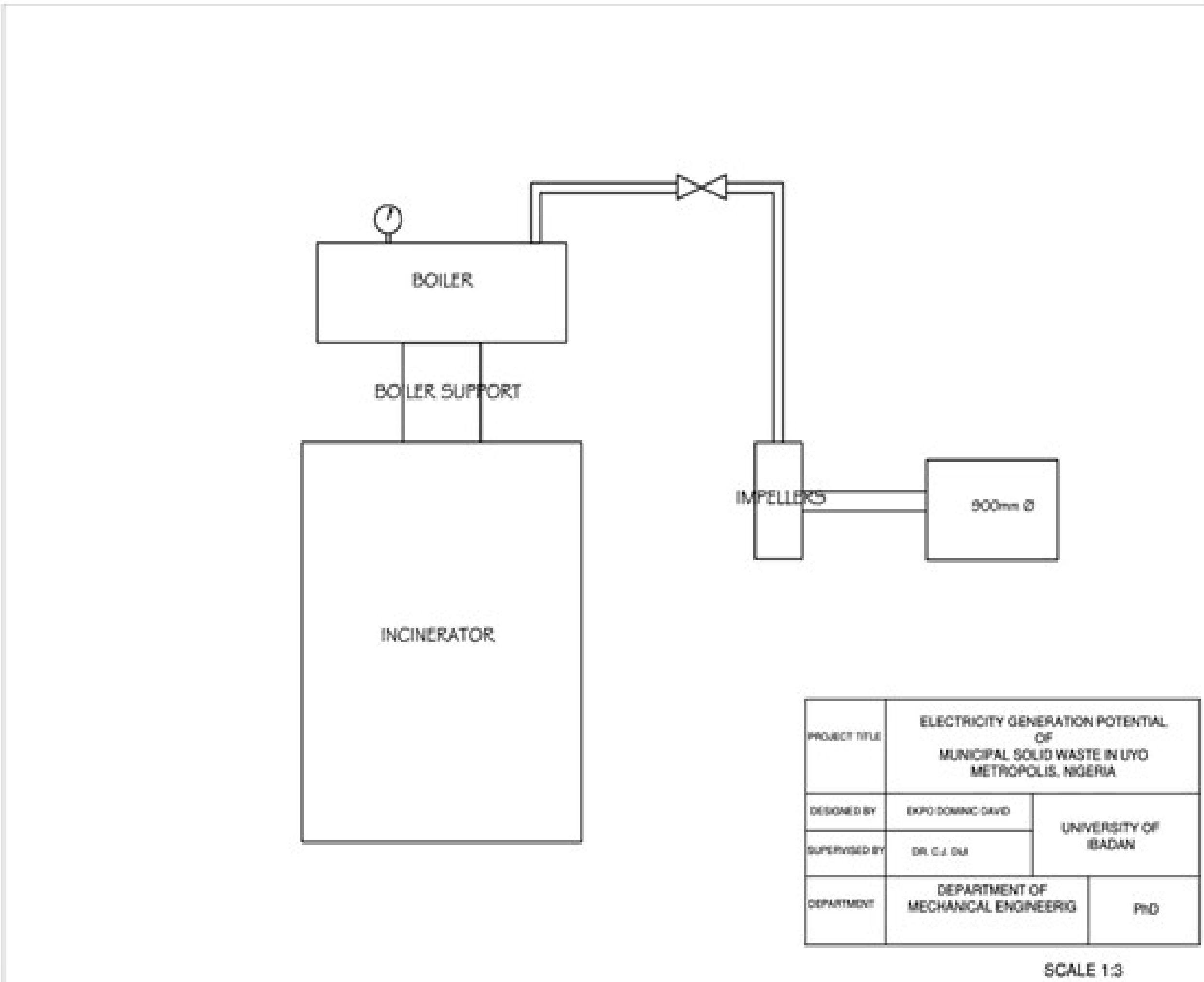
# APPENDICES

**Bills of Engineering Measurement and Evaluation**

| S/N | ITEM | DESCRIPTION | QUANTITY | UNIT PRICE (N̶) | AMOUNT (N̶) |
|---|---|---|---|---|---|
| 1. | Mild steel plate | 1220mm x 5mm | 1 roll | 12,500.00 | 12,500.00 |
| 2. | Angle iron | 5900mm x 6.50mm | 3pieces | 3,100.00 | 9,300.00 |
| 3. | Mild steel plate | 1220mm x 2.5mm. | 1 roll | 10,500.00 | 10,500.00 |
| 4. | Shaft | 1200mm x 250mm | 1 | 11,600.00 | 11,600.00 |
| 5. | Steel pipe | 12.50mm x 1220mm | 1 | 4,800.00 | 4,800.00 |
| 6. | Bearings | 250mm | 2 | 2,550.00 | 5,100.00 |
| 7. | Bolts and nuts | 12mm | 12 | 150.00.00 | 1,800.00 |
| 8. | Bolts and nuts | 10mm | 8 | 100.00 | 800.00 |
| 9. | Pulley | 300mm,100mm dia | 2 | 2,800.00 | 5,600.00 |
| 10 | Electric motor | 2HP 1420rpm | 1 | 19,200.00 | 19,200.00 |
| 11 | Miscellaneous | | | | 17,000.00 |
| | | | | **TOTAL** | 98,200.00 |


30mm Ø
750mm
750mm
150mm
100mm Ø
350mm Ø
300mm
150mm
750mm
250mm Ø
40mm
1200mm
900mm Ø
PROJECT TITLE
ELECTRICITY GENERATION POTENTIAL
OF
MUNICIPAL SOLID WASTE IN UYO
METROPOLIS, NIGERIA
DESIGNED BY
EKPO DOMINIC DAVID
SUPERVISED BY
DR. C.J. DUI
UNIVERSITY OF
IBADAN
DEPARTMENT
DEPARTMENT OF
MECHANICAL ENGINEERIG
PhD
SCALE 1:3


BOILER
BOILER SUPPORT
INCINERATOR
IMPELLERS
900mm Ø
PROJECT TITLE
ELECTRICITY GENERATION POTENTIAL OF MUNICIPAL SOLID WASTE IN UYO METROPOLIS, NIGERIA
DESIGNED BY
EKPO DOMINIC DAVID
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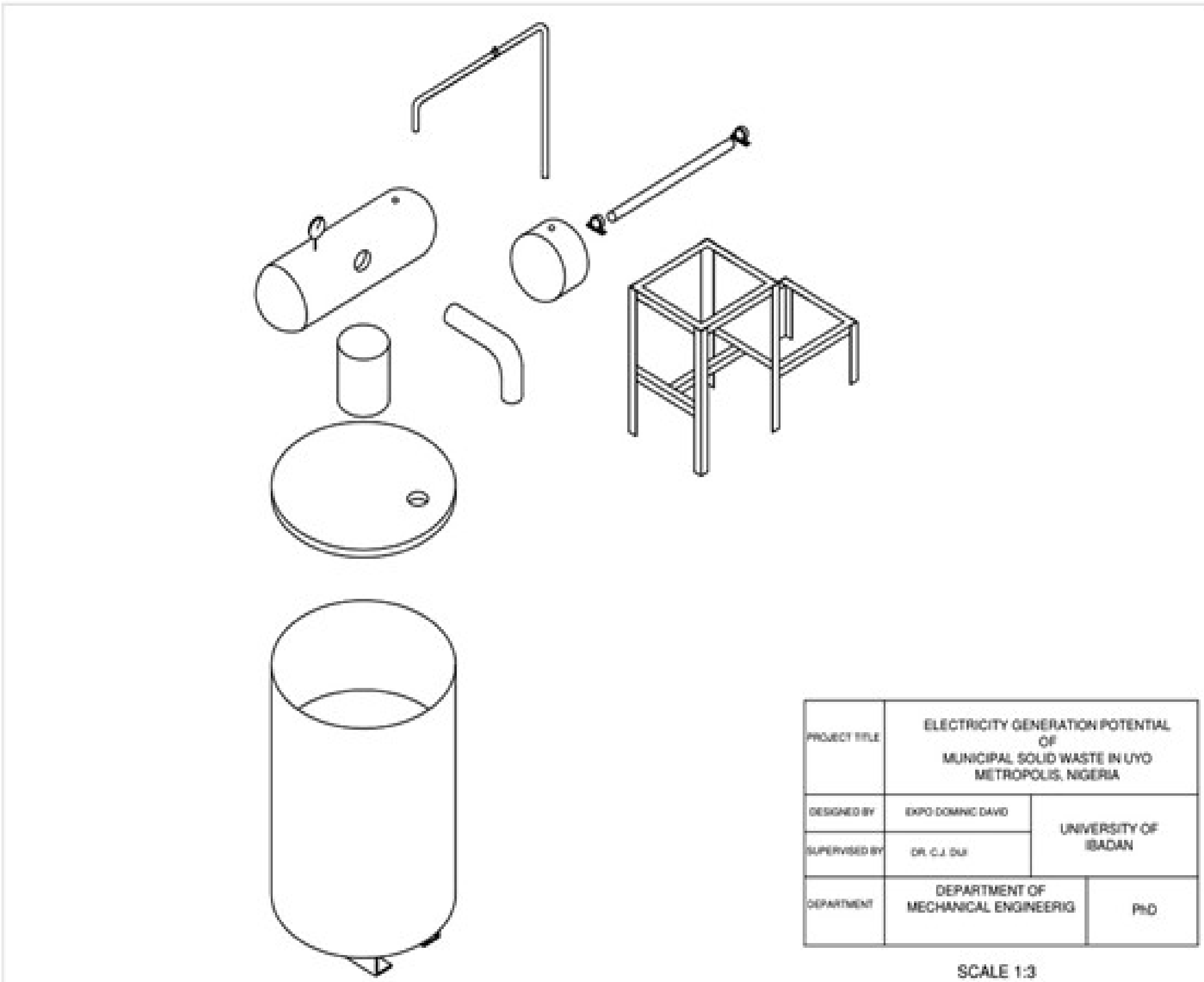
SCALE 1:3


PROJECT TITLE
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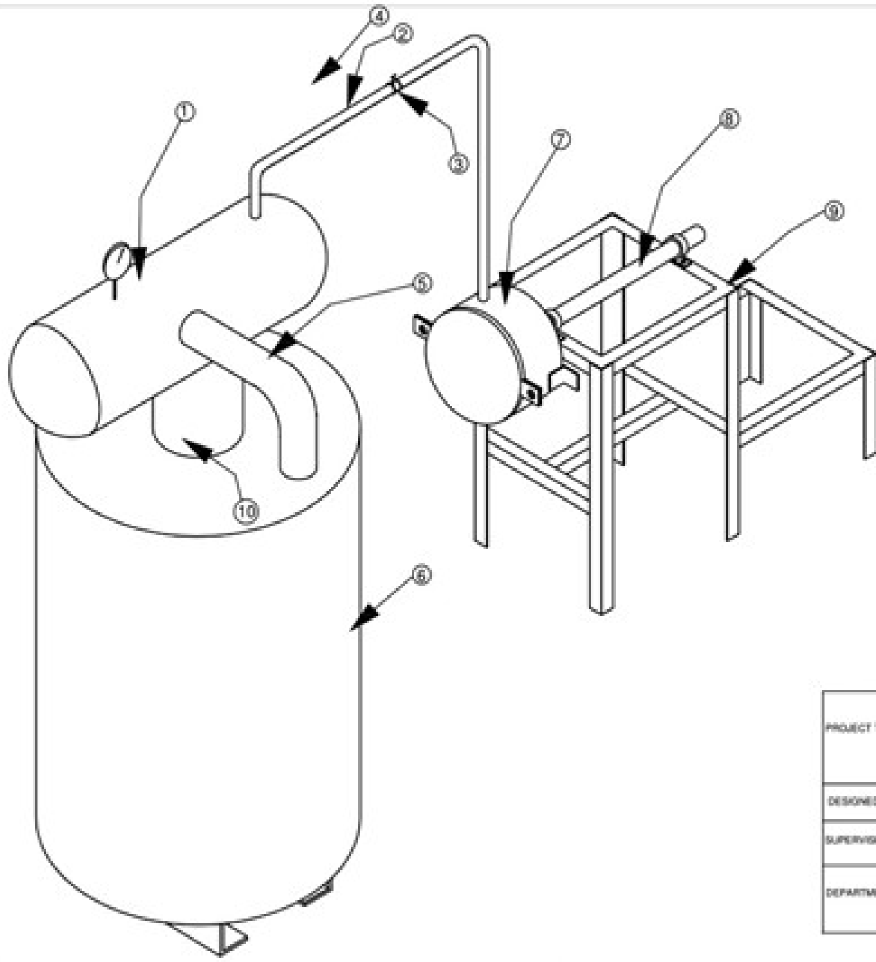
SCALE 1:3




| PARTS LIST | | |
|---|---|---|
| ITEM | DESCRIPTION | MATERIAL |
| 1 | Boiler | Mild Steel |
| 2 | Pipe connecting Turbine | Mild Steel |
| 3 | Outlet Gate valve | Mild Steel |
| 4 | Pressure gage | Mild Steel |
| 5 | Outlet Pipe | Mild Steel |
| 6 | Incinerator | Mild Steel |
| 7 | Impellers | Mild Steel |
| 8 | Turbine Shaft | Mild Steel |
| 9 | Main Frame | |
| 10 | Boiler Support | |

| | | |
|---|---|---|
| PROJECT TITLE | ELECTRICITY GENERATION POTENTIAL OF MUNICIPAL SOLID WASTE IN UYO METROPOLIS, NIGERIA | |
| DESIGNED BY | EKPO DOMINIC DAVID | UNIVERSITY OF IBADAN |
| SUPERVISED BY | DR. C.J. DIJI | |
| DEPARTMENT | DEPARTMENT OF MECHANICAL ENGINEERIG | PhD |

SCALE 1:3