Addis Ababa University

Addis Ababa Institute of Technology

Biomedical Engineering Department

Evaluation of Energy Potential from solid medical waste at Tikur Anbessa Specialized Hospital

A Thesis Submitted to the Center of Biomedical Engineering in Partial Fulfillment of the Requirement of the Degree of Masters of Science in Bio-medical Engineering

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September, 2018

Addis Ababa, Ethiopia

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Acknowledgment

First, I want to express my deep gratitude to the person who guided me throughout this entire process with me on the analysis of the technical and experimental portion of this thesis my advisor Dr. Ing. Wondwossen Bogale. Then, I also want to thank co-adviser Dr. Masreshaw Demelash for sharing his vast technical knowledge

This thesis is the result of the indirect and direct contribution, assistance, support, and trust from many individuals specially Dawit Mussie, Habtamu Demissie, and Tsegaye Demsis. Thanks to my classmates for all the daily talks and discussions we had helped me grow professionally.

Thanks to each of my colleagues from the Ethiopian Geological survey Laboratory for the determination of heating value and proximate analysis determination and Addis Ababa University; Department of Chemistry.

Lastly; I want to give huge thanks to my parents, who have always supported me with love, who are always present and willing to help, and who have raised me to be the person I am today.

Acronyms

AAU – Addis Ababa University

CSA – Central Statics Agency

EC – Ethiopian Calendar

EIA – Environmental Impact Assessment

EPA – Environmental Protection Authority

ESP – Electrostatic Precipitator

FC – Fixed Carbon

FEPA – Federal Environmental Protection Authority

FGR – Flue Gas Recirculation

FMOH – Federal Ministry of Health

G.C – Gregorian calendar

GHG – Green House Gas

HCW – Health Care Waste

HCWM – Health Care Waste Management

HHV – High heating Value

OPD – Out Patient Door

IPD – Inpatient Door

LP – Low Pressure

LHV – Low Heating Value

MSW – Municipal Solid Waste

MW - Medical Waste

MWM – Medical waste management

RDF – Refused derived fuel

SHEA – Society for Hospital Epidemiology of America

SNCR – Selective Non Catalytic Reduction

SMW – Solid Medical Waste

USEPA – United States Environmental Protection Agency

WTE – Waste to Energy

WHO – World Health Organization

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Abstract

The waste-to-energy conversion processes are expected to play an increasing important role in sustainable management of solid waste. The primary function of waste-to-energy technology has been volume reduction and power production.

Waste management has become a critical issue as solid waste possesses potential health risk and damage to the environment. Management of solid medical waste has not yet got the priority it deserves. Researches indicated that in the past solid waste has done much damage to the environment and to public health. As we know Tikur Anbessa Specialized Hospital is the biggest hospital in Ethiopia. But the managing of solid medical waste is poor, even practice of incineration is very old and it is not environment friendly. The general objective of this study is to assess waste management practices and to evaluate the amount of energy that can be generated from solid medical waste at Tikur Anbessa Specialized Hospital. The methodologies are descriptive and consist of the use of survey, in depth interviews, meeting, discussion and participant observed strategy with the concerned body of the hospital. It also involved in the identification and characterization (type and laboratories work) of waste type. After characterization Thermoflex software was used to estimate the power output.

The result shows that the average solid medical waste generation rate was determined 1396.41 kg/day from this about 68.26 % was food waste, 14.68 % was plastic waste, 12.84 % was paper waste, 2.99 % was wood waste and 1.23% was cloth waste. The annual estimated waste generation was 507,923.57 kg or 507.9 tons. In general solid medical waste management was found in poor manner. The gross and net electric power output for a mass flow rate of 0.217 kg/s was 0.84MW and 0.731MW respectively. Based on the result, the net electric efficiency of the system was 18.96%. Based on the result the system was affected by ash content, moisture content, excess air and lower heating value here of optimizing input parameter then was increased power output from 840.6 kW to 891.3kW or 0.84MW to 0.89MW. To optimize the power output we can reduce boiler exit temperature and condenser pressure. And also minimizing of ash content and moisture content are improving the output.

Key words: Solid Medical Waste, Generation rate, Waste-to-Energy, Power

Chapter One

Introduction

1.1. Background of the study

Health-care waste is a by-product of health-care activities that includes sharps, non-sharps, blood, body parts, chemicals, pharmaceuticals, medical devices, and radioactive materials (Morales 2013). Society for Hospital Epidemiology of America (SHEA), defined it as "materials generated as a result of patient diagnosis, treatment, or immunization of human beings or animals"(Martini 1993: 208). The American Environmental Protection Agency (EPA), defined medical waste as “any solid waste which is generated in the diagnosis, treatment,' or immunization of human beings or animals, in research pertaining thereto, or in the production or testing of biological”.

Mismanagement of health-care waste is a significant problem in developing countries. Health-care waste has not received adequate attention even though it is labeled as hazardous or infectious waste (Alagöz et al. 2008; Da Silva et al. 2005; Jang et al. 2006; Tsakona et al. 2007).

Health-care waste management (HCWM) in the world is a formal discipline and does occupy a significant place in the management of the health-care sector. The proper management of hospital waste requires that segregation, on-site collection and transportation, storage, incineration, off-site collection and transportation and final disposal of waste from all health-care facilities should be done as safely, hygienically, and economically as possible and all stages should also minimize the risk to public health and the environment.

Considering this issue as a major concern, many researchers in developing countries have studied the existing health-care waste management (HCWM) status, practices, and issues in selected health-care facilities within their countries and have mentioned different reasons for poor hospital waste management status and practices in their publications, see for example (Bdour et al. 2007; Coker et al. 2009; Da Silva et al. 2005; Hassan et al. 2008; Kumar et al. 2010; Marinković *et al*. 2008; Nemathaga *et al*. 2008; Pescod etal. 1998).

A study from Turkey shows lack of sufficient budget allocation from government, lack of awareness and training, and high expense of treatment/disposal "Compliance with regulations or guidelines by many health-care facilities remains a problem in all countries due the lack of proper enforcement regimes" (de Titto *et al*. 2012: 560).

In Ethiopia, health-care facilities are increasing in number. Health-care services and infrastructure such as number of beds, capacity of handling more number of patients, etc., in the hospitals also are increasing. Such a growth in the health-care infrastructure and services may possibly increase the generation of the HCW that needs to be the quantified and characterized.

Any type of waste such as; municipal waste, industrial waste, electronic waste, biomass, or medical waste the way in which we as a society deal with unwanted materials represents an important material and representative intersection between the environmental, economic and social aspect of our society. Waste is currently at the heart of many of our environmental problems but when addressed through ecologically sustainable practices can dramatically reduce resource consumption, energy use, and carbon pollution while becoming a valuable economic and agricultural resource (Lee Bell and Jane Bremmer, 2013).

Waste-to-energy plants are mostly seen as a means to bridge the gap between sustainable environment and energy supply. The plants serve the dual objectives of reducing the amount of waste sent to landfills and simultaneously producing useful energy. (Lausselet et. al., 2016)

Waste-to-Energy technologies consist of any waste treatment process that creates energy in the form of electricity, heat or transport fuels from a waste source. These technologies can be applied to several types of waste: from the solid, liquid and gaseous waste. However, the most common application by far is processing the Municipal Solid Waste (MSW) (Eurostate, 2013). The current most known WTE technology for MSW processing is incineration in a combined heat and power plant. (World energy resource, 2013)

The Koshe- Reppie waste-to-energy plant has been constructed on the area of 7 hectares from the total of 37hectares of damping site and the power has established 50M/day according to the project agreement. Nevertheless at end of project the net power produced is 25M/day.

A vast majority of research studies published to this date on electrical energy and heat recovery have been concerned with large municipal solid waste incineration systems. Only few of the publications presented the research on electrical energy and heat recovery in small and medium incinerating medical waste. They were focused on the production of syngas or waste gasification and its combustion in gas engines (Janusz Wojciech, 2015).

Therefore wastes can harmful for worker and the public as well as the environment. However if the solid medical waste will change to energy with economical and environmentally friendly it has an important role on waste minimization and advantage on conversion to steam and electricity.

Clarification of Basic Terms and Concepts

- Medical waste or health-care is waste generated from health institutions. This includes both infectious waste and non-infectious waste materials. Medical waste is also referring to as Health-care waste, hospital waste or clinical waste (Soncuya, 1997; WHO, 2005; WHO, 2014).
- Non infectious waste is a waste that does not pose a health risk (Soncuya, 1997; WHO, 2014)
- Infectious waste includes infectious materials that can cause disease to humans (WHO, 2005). Infectious waste means health-care risk waste which is suspect to contain pathogens and which normally causes or significantly contributes to the cause of increased morbidity or mortality of human beings and includes but is not limited to sharps waste and anatomical waste; but excludes baby nappies and sanitary pads (Godey, 2003).
- Medical waste management or healthcare waste management is a process that helps ensure proper hygiene in the health institution and safety of health-care Workers and communities (Sanitation Connection, 2002)
- Waste disposal refers to the final placement of treated waste (Johannessen *et. al.*, 2005; WHO, 2005).

- Treatment of wastes is mainly reducing direct exposure of waste to become less dangerous to humans, at recovering recyclable materials and at protecting the environment (Johannessen *et. al.,* 2005).

- WTE Technology is any waste treatment process that creates energy in the form of electricity, heat or transport fuels from a waste source (world energy council, 2013).

1.2. Health impacts of medical waste

Medical waste includes a large component of general waste and a smaller proportion of hazardous waste (Tadesse, 2015; Abdul-Salam, 2009). The hazardous nature of health-care waste may be due to one or more of the following characteristics:

- It contains infectious agents;
- It is geotaxis;
- It contains toxic or hazardous chemicals or pharmaceuticals;
- It is radioactive;
- It contains sharps.

Persons at risk

All individuals exposed to hazardous health-care waste are potentially at risk, including those within health-care establishments that generate hazardous waste, and those outside these sources who either handle such waste or are exposed to it as a consequence of careless management. The main groups at risk are the following:

- medical doctors, nurses, health-care auxiliaries, and hospital maintenance personnel;
- patients in health-care establishments or receiving home care;
- visitors to health-care establishments;
- workers in support services allied to health-care establishments, such as laundries, waste handling, and transportation;
- Workers in waste disposal facilities (such as landfills or incinerators), including scavengers.

1.3. Environmental impact of health-care waste

Hazardous health-care waste is adversely affect city environment all over the world particularly developing countries are most at risk due to poor waste management. Health-care facilities in an urban area are designed as a place for patients for diagnosis, analysis and treatment of medical problems. It houses a number of complex activities where generation of solid waste is unavoidable. (Nikos *et al*., 2006; SEYEID, 1993)

1.4. Social impacts of medical waste

Considering the social issues the social sensibility starts from the disposal of health-care wastes. Quite apart from fear of health hazards, the general public is very sensitive about the visual impact of anatomical waste, which is recognizable human body parts, including fetuses. In no circumstances is it acceptable to dispose of anatomical waste inappropriately, such as on a landfill (DELIA, 2009).

1.5. The Statement of Problem

Waste management has become a critical issue as it poses potential health risks and damage to the environment. An issue is taking central place in the national health policies of many countries. In developing countries, solid wastes have not received sufficient attention. This is because very often, health issues compete with other sectors of the economy for the limited resources available. Thus, management of solid medical waste has not yet got the priority it deserves.

In many countries hazardous municipal and solid medical wastes are still handled and disposed together with domestic waste that posing a great health risk to health workers, municipal workers, the public and as well as the environment. Solid medical wastes must be separate from municipal waste but in many parts of Africa, it tends to be collected along with the rest of the waste stream (Kgathi and Bolanee, 2001).

Researches indicated that in the past, solid medical wastes have done much damage to the public health and to environment. Evidence concerning health problems related to poor medical waste management indicate that, in 2003 the occurrence of a severe outbreak of acute respiratory syndrome in Taiwan enforced the authorities to take more serious steps in managing solid medical wastes (TEPA, 2003). Study indicates a clear association between exposure to incinerator emissions and ash increased adverse health impacts because of high amount of heavy metals. Studies conducted in Japan, Spain, and Germany show that incinerator workers or children and other residents living near incinerators have significantly higher blood or urine levels of dioxins, furans, and hydrocarbons compared to control groups or to national averages (Kumagai et. al., 2005).

Ethiopia is one of the least developed countries in the world [UNDP, 2010, Gwénaëlle, 2009]. It has one of the lowest rates of access to modern energy services; its energy supply is primarily based on biomass. With a share of 92.4% of Ethiopia's energy supply, waste and biomass are the country's primary energy sources, followed by oil (6.7%) and hydropower (0.9%) [IEA, 2008]. Tikur Anbesa Specialized Hospital is the biggest hospital in Ethiopia, the service capacity of this hospital is 3.5-5.0 million. So as the number of patients are directly related to waste generation. That means number of patient and waste generation is directly proportional. So if we convert this medical waste to energy we get an advantage of reduction of co_2 emission from incineration, reduction of medical waste disposal, use of renewable low cost feedstock, and use of sustainable method to convert waste into useful product.

Large urban hospitals generate more than a million tons of waste each year. Yet many hospital in developing countries dump all waste streams together, from reception area trash to operating room waste and burn them together in incinerators. Over the years the world has learned that incineration is a leading source of air pollutants that threatens human and the environment. Moreover, some urban and many rural hospitals and clinics in the developing world simply discard their medical waste with regular trash and risk the spread of diseases among scavenger populations. Discarded needles and syringes may result in the spread of blood borne pathogens such as HIV and hepatitis. Other burn their waste in open dumps or in small incinerators without pollution control, exposing communities downwind to toxic byproducts such as dioxins and mercury, and generating potentially hazardous ash. In the basis of the above problems the case needs a robust and environmental friendly waste-to-energy technology.

1.6. Objectives

1.6.1. General objectives

The general goal of this study is to identify the current management practice and evaluate the energy potential of medical waste at Tikur Anbessa Specialized Hospital.

1.6.2. Specific objectives

- To quantify and characterize the types and amount of solid medical waste generation rate
- To assess the current solid medical waste management practice (collection, storage, transport, treatment and disposal of health care wastes)
- To optimize and to perform sensitivity analysis waste to energy technology
- To estimate electricity generation potential from solid medical waste in Tikur Anbessa Specialized Hospital

1.7. Scope of the study

This study was conducted in Tikur Anbessa Specialized Hospital to quantify, characterize and estimate of Solid Medical Waste-to-Energy. It requires a wide scale study in different hospitals of the country. But, with the available time and resource in order to make the study more manageable its scope is delimited to Tikur Anbessa Specialized Hospital on solid waste.

1.8. Organization of the Research Paper

This thesis has five main chapters. Chapter one is an introduction part which consists of the introduction, statement of the problem, the objectives, and the scope of the study. Chapter two presents the review of related literature. Chapter three describes the study area and the research methodology. Chapter four contains the analysis, results and discussion parts of the study and the fifth chapter presents the conclusion and recommendations of the study.

Chapter Two

Review of Related Literature

This chapter provides a review of the literature that already exists in relation to the waste to energy technology and management of solid medical wastes; which as a negative externality is one of the major environmental problems in not only Ethiopia but the world as a whole. Initially, this chapter will discuss about the management of solid medical wastes in various hospitals, it will then move on to analyses the willingness to pay for better solid medical waste management in different hospitals. This chapter will also provide a review of the waste to energy technology types. Finally, the costs incurred in the treatment and disposal of medical waste have been considered in the last part of this chapter.

2.1. Healthcare Waste Management

Waste is a material discharged and discarded from each stage of daily human life activities, which leads to adverse impacts on human health and the environment (Bringi, 2007). Whereas, Hospitals produce a tremendous amount of medical waste that is defined as any solid waste which is generated as a result during patient diagnosis, treatment, or immunization of humans or animals.

In Ethiopia, there is no specific HCWM legislation. However, there are policies and legislations with provisions that may offer a legal frame for the management of health-care waste (MOH, 2008).

The Ethiopia Environmental Pollution Control Proclamation, No300/2002, after defining hazardous waste as "an unwanted material that is believed to be deleterious to human safety, health or the environment pronounces the following prohibitions and restrictions in its management". No person shall pollute or cause any other person to pollute the environment by violating the relevant environmental standards" (Article 3-sub article, 1).

Concerning the management of hazardous waste, it states that the generation, keeping, storage, transportation, treatment or disposal of any hazardous waste without a permit from the

Environmental Protection Authority or the respective Regional Environmental Agency is prohibited (Environmental Pollution Control Proclamation,No.,300/2002).

The Ethiopia Public Health Proclamation No.200/2000 pronounces the following prohibitions and restrictions about hospital waste “Any solid, liquid and other wastes generated from hospitals should be handled with special care and their disposal procedures should meet the standards set by the public health authorities”. The proclamation neither provided a clear definition of the various categories of HCW nor did it indicate the legal obligations that HCW producers have with regard to segregation, safe handling, treatment and disposal. In addition, it did not indicate specifications for record keeping and reporting, and inspection systems for enforcement of the law (Public Health Proclamation, 2000).

The Environmental Impact Assessment Proclamation No.299/2002 requires proponents to undertake Environmental Impact Assessment (EIA) for those projects considered to have significant environmental impacts and listed as such in directives issued pursuant to this proclamation. According to the EIA guideline issued by the Federal Environmental Protection Authority (FEPA), large HCW incineration facilities, chemical treatment facilities and landfills for toxic, hazardous and dangerous wastes are among the list of projects considered to have adverse and significant environmental impacts and hence require full environmental impact assessment (Federal Environmental Protection Authority, 2000).

Incinerator emissions are a major source of fine particulates, of toxic metals and of more than 200 organic chemicals, including known carcinogens, mutagens, and hormone disrupters. Emissions also contain other unidentified compounds whose potential for harm is yet unknown, as was once the case with dioxins. Since the nature of waste is continually changing, so is the chemical nature of the incinerator emissions and therefore the potential for adverse health effects (Jeremy and Honor, 2008).

According to my previous work (2016) was conduct to quantify waste generation rate, composition, level of heavy metals and evaluate its management system on Tikur Anbessa Specialized Hospital, Yekatit 12 Hospital and Gandhi Memorial Hospital. According to this study the result shows that the mean healthcare waste generation rate was 12.41kg/day of which (56.3%) 20.96kg/day was non-infectious waste and (43.7%) 16.27kg/day was infectious.

The overall heavy metals concentration were high concentration of copper was found to be very high in comparison to other metals and the descending order was Cu>Pb>Cd>Cr. A wide variation in trace concentration of several toxic elements has also been seen due to variation in initial waste composition, design of the incineration, the level of hospital and operating conditions (Azeb, 2016).

2.2. Increasing Global Waste Generation

According to the World Bank, the world generates about 4 billion tons of all types of waste per year. The world's cities alone generate about 1.5 billion tons of solid waste per year. This volume is expected to increase to 2.4 billion tons by 2025. In lower income countries, waste generation will more than double over the next 25 years. Three-fourths of this waste is disposed of in landfills, with only one fourth being recycled. (World Bank, 2012).

2.3. Increasing Energy Demand

In addition to increasing waste generation, the global demand for energy will increase by 56 percent between 2010 and 2040, with the greatest demand in the developing world (US Energy Information Administration 2013). According to the World Bank, there are currently 1.2 billion people (20% of the world's population) without access to electricity (World Bank-Energy Facts).

2.4. Health-care Waste Treatment Options

The many available waste treatment options for health care waste treatment may be classified into four processes: thermal (including incineration), chemical (using disinfectants), and irradiative (using ionizing ration), and biological (using enzymes). These processes are generally used in conjunction with mechanical shredding, compaction and mixing to render waste unrecognizable, to improve heat or mass transfer, and/or to reduce the volume of treated waste. Reviews of health care waste treatment options are provided elsewhere (Prüss 1999; HCWH 2001). The selection of appropriate treatment options depends on many factors including (HCWH 2001):

- Throughput capacity
- Types of waste treated
- Microbial inactivation efficacy

- Environmental emissions and waste residues
- Regulatory acceptance
- Space requirements
- Utility and other installation requirements
- Waste reduction
- Occupational safety and health
- Noise
- Odor
- Automation
- Reliability
- level of commercialization
- background of the technology manufacturer or vendor
- Costs (both initial and operating)
- Community and staff acceptance

HCWH (2001) and others point out that no one technology is a panacea to the problem of health care waste, and that each technology has its advantages and disadvantages.

2.5. Evaluating Technological Options

The various technologies should be evaluated using comparable health, environmental and economic criteria. Often, this is difficult given uncertainties but it is possible to describe possible risks, benefits and costs. Importantly, the feasibility and desirability of most waste treatment options will likely depend on waste volumes currently generated and trends for the near-term. In their evaluation, waste generators ideally should undertake a waste audit, formulate appropriate indicators to assess and forecast waste generation trends, and assume moderate-to-intensive efforts to minimize waste (depending on current minimization efforts).

The following criteria are suggested in evaluating small-scale treatment options for health care waste:

- **Effectiveness:** Wastes should be completely sterilized and rendered into a form that prevents hazards or reuse

- **Cost-effectiveness:** The technology should be economically competitive with other available options. A life-cycle cost basis that accounts for all costs, e.g., capital, operating, training, regulatory, energy, liability, waste disposal, etc.
- **Safety:** The construction, operation, and closure of the technology/facility should not present unacceptable environmental or human health risks. This includes consideration of occupational, community and environmental risks resulting from any air emissions, water effluents, and solid wastes generated.
- **Simple:** technologies for poor countries should ideally be easy to manufacture, operate and maintain.
- **Robust:** The technology should consistently meet air emission and other health and safety criteria under a wide variety of operating conditions.

WHO has a larger list of factors to guide the choice of treatment system, noting that many of them depend on local conditions list of criteria (Prüss 1999):

- disinfection efficiency
- health and environmental considerations
- volume and mass reduction
- occupational health and safety considerations
- quantity of wastes for treatment and disposal/capacity of the system
- types of waste for treatment and disposal
- infrastructure requirements
- locally available treatment options and technologies
- options available for final disposal
- training requirements for operation of the method
- operation and maintenance considerations
- available space
- location and surroundings of the treatment site and disposal facility
- investment and operating costs
- public acceptability
- regulatory requirements

2.5.1. Incineration of health-care waste

Incineration is a high-temperature dry oxidation process that reduces organic and combustible waste to inorganic, non-combustible matter and results in a very significant reduction of waste volume and weight. The incineration process detoxifies hazardous wastes by destroying most of the organic compounds contained in the wastes. Organic compounds burn over a broad range of temperatures, forming carbon dioxide, water and products of incomplete combustion, some of which may be more toxic. This process is usually selected to treat wastes that cannot be recycled, reused, or disposed of in a landfill site (F. Powell, 1987) The key system elements involved in the incineration of medical wastes includes: combustion chambers, bottom ash removal system, and gas cleaning equipment (J. J. Santoleri, 2009)

Incineration system depends significantly on the extent to which basic combustion process requirements are successfully met. In principle, these requirements include capability to process variety of non-homogeneous wastes of different chemical compositions, physical dimensions, densities, moisture contents and heat values. Minimal carry-over of particulate matter into the off-gas is inevitable. Monitoring of process parameters and composition of the off-gas at the exit from the combustion part of the system and consistent quality of ash having desirable physical characteristics is required (S. V. Manyele, 2004)

To achieve a high degree of combustion of the waste in a combustion system it is necessary to ensure the presence of an adequate combustion temperature, a sufficient excess supply of air, an ample mixing of the air and the thermal decomposition gas, and an adequate reaction time. In a successful incinerator design, careful consideration is given to the provision of adequate excess air and the appropriate location of the air supplies; the combustion temperature is carefully controlled; the gas flow velocities through the combustion chamber are adequately low; and the gas and solid waste residence times in the combustion chamber are of sufficient duration (IAEA, 1992)

It is more preferable to employ two combustion chambers connected in series, whereby the waste is loaded into the primary chamber where it undergoes thermal decomposition followed by a secondary combustion chamber (afterburner) for oxidizing the remaining gases and volatile compounds. A support burner and additional air injection equipment are usually required in the secondary chamber to maintain a sufficiently high and consistent temperature. (IAEA, 1992)

The primary combustion chamber houses the fixed grate or hearth, waste charging door, ash removal doors, air inlet pipe from the blower and primary burner. Initial burning of waste occurs in this chamber, with combustion air supplied in the grate area by a combustion air blower. Partial combustion occurs in the primary chamber, with the hot gases generated flowing up into the secondary combustion chamber. The temperature within the primary chamber is maintained around 750˚C - 900˚C by controlling the combustion air and the firing rate of the burner producing solid ashes and gases. Further combustion of the gases occurs in the secondary combustion chamber which is usually located above the primary chamber. Secondary combustion is augmented by an auxiliary burner, with air Supplied by additional vents or blowers. To minimize pollution, smoke and odors in the environment, the temperature within the secondary chamber is maintained at 900˚C - 1200˚C, and the residence time at a minimum of two seconds. The combustion gases exit the secondary chamber to the stack or an air pollution control device (APCD) for cleaning before it joins the environment (R. Walter, 2002).

Combustion requires high temperature to produce enough combustible gases, enough oxidant (air) for thorough oxidation, enough turbulence in the combustion gas mixture and the air mixture held at high temperature for long residence time to allow complete oxidation (V. J. Landrum, 2009). Exhaust gas temperatures from the incineration systems are typically as high as 1100˚C. At these temperatures, energy is recovered and help in reducing most of the operating costs especially fuel costs (L. J. Zhao, 2010)

Waste characterization and practical considerations in incinerator design are the important factors for improved incinerator performance. Solids which have a high heating value and are finely divided like sharps waste tends to ignite explosively. Thermo plasticity is another character to be considered, unique to solid materials which create serious problems in the combustion of solid waste. Waste material softens and melts before it burns and adheres to feeders, refractory linings in the incinerator and the grates where air is introduced. It then burns slowly, often incompletely, and tends to render other solids immobile by “gluing them together” into low surface area masses. Such materials need to be mixed, before feeding, with non-thermoplastics waste quantities to eliminate the adverse effects of thermo plasticity (J. D. Brady, 2007)

2.5.2. Waste-to-Energy (WTE)

Waste to Energy (WTE) entails the process of combusting waste under controlled conditions as a means of recovering energy in the form of electricity or heat. The concept is believed to have originated from Europe, from where it spread to Asia and North America (Rogoff, 1987). In the past, mass-burn incineration technology has been the main method for recovering energy from waste. In recent years, several technologies have evolved that aids the energy from waste recovery process. These include pyrolysis, gasification and anaerobic digestion (Porter, 2002; Young, 2010; Sorensen & Breeze, 2009). WTE initiatives reduce the volume of waste by as much as 90%, thereby easing the pressure on landfills (Sorensen & Breeze, 2009). WTE plants also have the potential to generate employment. In spite of its benefits, there are several challenges associated with the WTE concept chief amongst which include the discharge of dioxins and heavy metals into the environment (Sorensen & Breeze, 2009). The financial cost of constructing, operating and maintaining a WTE plant is also seen as a major difficulty (Sorensen & Breeze, 2009). In spite of such challenges, the concept of WTE has gained traction in the waste management concept.

2.5.2.1. Benefits of Waste-To-Energy

Some of the benefits of WTE compared to land filling: (Tajirul, 2016)

- **Economically Preferable:** The cost of WTE depends on the technology as well as location and other factors. The benefits result from avoiding the cost of garbage transportation and land filling, while at the same time generating energy that has monetary value. We can save the significant cost of trucking waste to landfills as most major landfills are fairly distant from main city centers.

- **Conserves Natural Resources:** WTE avoids the consumption of natural resources like oil, gas, and coal which are otherwise used to generate energy. For example, a single WTE facility (Huntsville Waste to Energy facility) saves over 200,000 barrels of oil per year.

- **Better Recovery of Materials:** In WTE, metals left in the waste stream can be extracted from the residue resulting from combustion and the output can be recycled.

- **Less Impact on Climate:** WTE has a number of environmental benefits. WTE produces less greenhouse gas. Methane is a greenhouse gas which is mainly emitted from the decomposition of the waste stream in landfills. It is over 20 times more potent than carbon dioxide and is one of the most notable contributors to climate change. In WTE facilities, the production of methane is avoided. Currently, WTE facilities in the U.S. account for around 20% of renewable electricity generation.

- **Creates Jobs**: The Energy Recovery Council states that an average WTE facility in the U.S. creates 58 full-time jobs with at least 40 years of projected operation life. As such, the benefits of WTE demonstrate how WTE can solve our waste disposal problems and at the same time supply a renewable source of energy.

2.6. Energy in Ethiopia

Most of the electricity in Ethiopia is produced and delivered from hydropower plants. Power supply is not sufficient in Ethiopia and, transmission problems often lead to failure in power supply. In 2016 the electricity production in Ethiopia has approximately 2,300MW to serve a population of over 95 million people, from hydroelectric, wind, solar and geothermal sources

The country there was a severe power shortage due to the low limited rainfall. To reduce the dependency on hydropower investments are also made in thermal plants, wind, solar and biogas electric power from.

The Reppie project an incineration plant for energy production from combustion of municipal solid waste from Addis Ababa. "The Reppi landfill project demonstrates that carbon finance has the potential to achieve triple wins for sustainable development. The project demonstrates a combination of economic benefits, social benefits, and environmental benefits. Firstly, carbon credits are helping to make economically viable a project that would not otherwise happen bringing additional revenues to the City of Addis Ababa. Secondly, social benefits arise from green jobs which will be created from scavengers who currently live on the landfill. Thirdly, the project delivers important environmental benefits through reducing greenhouse gases that would otherwise be emitted into the atmosphere contributing to global warming," (John, 2015)

The Koshe-Reppie waste-to-energy plant has been constructed on the area of 7 hectares from the total of 37hectares of damping site and the power has established 50MW/day. The facility is being operational the likely sources of negative and positive from waste-to-energy are leachate from storage and handling of municipal solid waste. Different individual and institutions in different time studies showed that about 60-70 percent of Addis Ababa city's solid waste composition is organic waste. These solid wastes mainly contain vegetables and food wastes that contain high moisture. Such wastes with high moisture content are not suitable for incineration. (Massreshaw, 2017)

Figure 1. The construction site of Reppi (AACA)

Treatment of medical wastes in developing countries has commonly been carried out using different method and technologies such as open burning, open dumping, landfills, sanitary landfills, etc. On the other hand, there has been a growing appreciation of the functions of incinerators which are increasingly being used for the treatment of a variety of wastes. However, most of the medical wastes are treated with poor incineration technology and without caring about the emissions and ash disposal from the treatment sites. The utilization of substandard incinerators produces solid residues (ashes), which can be toxic or hazardous to the community and to the environment.

The most common methods used for all type of wastes are land filling (is a site for the disposal of waste materials by burial and is the oldest form of waste treatment. Historically, landfills have been the most common method of organized waste disposal and remain so in many places around the world.), composting, recycling, mechanical-biological treatment and waste-to-energy. (Abdulhakim, 2014)

Landfills have the potential to cause a number of issues. Infrastructure disruption, such as damage to access roads by heavy vehicles, may occur. Pollution of local roads and water courses from wheels on vehicles when they leave the landfill can be significant and can be mitigated by wheel washing system. Pollution of the local environment, such as contamination of ground water or aquifers or soil contamination may occur, as well.

According to WHO, the waste produced by hospitals carries a higher potential for infection and injury than any other kind of waste (WHO, 2005). Medical waste is a major problem in most developing countries of the world due to its growing and endless generation coupled with poor management (Alagoz and Kocasoy, 2008). The process of storing, collecting, transporting, treating and disposing waste material is known as waste management (Farzadkia et. al., 2009). The aim is to clean up the surrounding environment and realize that the waste does not have a detrimental effect on our health. Nowadays, waste management has gone a step further not only planning proper disposal but also attempting to see whether we can reuse and recycle certain materials from waste matter (Harhay et. al., 2009). The safe and effective disposal of medical waste starts with a healthcare practitioner. There is a real need to reduce both the cost and environmental impact arising from the generation and disposal of waste in healthcare settings (Royal, 2009).

In 2016, I have conducted a research to quantify waste generation rate, composition, level of heavy metals and evaluate its management system on Tikur Anbessa Specialized Hospital, Yekatit 12 Hospital and Gandhi Memorial Hospital. According to this study the result shows that the mean healthcare waste generation rate was 12.41kg/day of which (56.3%) 20.96kg/day was non-infectious waste and (43.7%) 16.27kg/day was infectious. The overall heavy metals concentration was concentration of copper was found to be very high in comparison to other metals and the descending order was Cu>Pb>Cd>Cr. A wide variation in trace concentration of several toxic elements has also been seen due to variation in initial waste composition, design of the incineration, the level of hospital and operating conditions (Azeb, 2016). However, in this study was not addressed waste to energy.

The study of energy by Janusz Wojciech Bujak stated that the research on the installation for thermal treatment of medical waste covered the components responsible for energy and heat. The study was conducted in a large hospital complex and was analyzed in terms of energy and economic aspects. In terms of energy, tests have shown the value of designing and building medical waste incineration systems with heat recovery, which, in addition to performing a basic utilization role, will also be highly efficient in terms of energy (Janusz Wojciech, 2015). A study of paper by Dean K., 1996 described heat recovery from hospital installations for the thermal neutralization of medical waste. He discussed possibilities for producing steam using waste heat from the incineration of medical waste. He proved that the use of such a heat recovery system significantly reduced the annual operational expenses of a hospital boiler room. Also studied by (Mori, Kikegawa and Uchida, 2007) presented a model for waste heat utilization, for instance, from the incineration plant in Tokyo. That model was applied to reduce the emission of carbon dioxide by approximately 8%.

2.7. Conceptual framework

The waste management process mainly revolves around the socio-environmental, economic issues, technical analysis and political decision making factors. The planners/solid waste professionals have in-depth knowledge about the technical issues of different waste-to-energy recovery technologies and are able to carry-out technical analysis, they have the ability to provide correct information and advice to political leaders, who are the decision making bodies for the implementation of waste-to-energy facility. However, the selection of appropriate waste-to-energy recovery facility mainly depends on socio-economic and environmental factors.

In the binging, it is important to define the system boundaries, which will involve what types of the waste planning activities will be considered during the solid waste management practice i.e. waste minimization, segregation, recycling of products, and the remaining waste is available for energy recovery technologies, which can be utilized to produce "green energy" in the form of heat and electricity etc. respectively has complex process. In the second step, the selection procedure depends on the available options i.e. waste-to-energy technologies, and generally given preferences to those technologies that is successfully operating locally, regionally and implemented worldwide. There must be criteria for selection of reasonable facilities according to local needs, mainly depends on a variety of important factors such as social, environmental, economic and technical issues. It is necessary to give more technical feedback on various technologies and local needs. The technical constrains play crucial role to predict the volume, type and quantity of generated solid waste which are suitable for specific type of waste-to-energy technology. The professionals or planners should carry out the monitoring and assessment of different types of available technologies by considering these important factors, and select the most efficient resource recovery options. These technologies could be either convectional or emerging facilities.

In the third step, through this strategy, each type of waste-to-energy recovery technology should be evaluated and ranked and then the recommendation should be forwarded to political decision makers. In the final step, results forwarded to politician decision body for final approval, they may give their decision either in-line with professionals/experts opinions or according to their own wills for an implementation of waste-to-energy technology in study area.

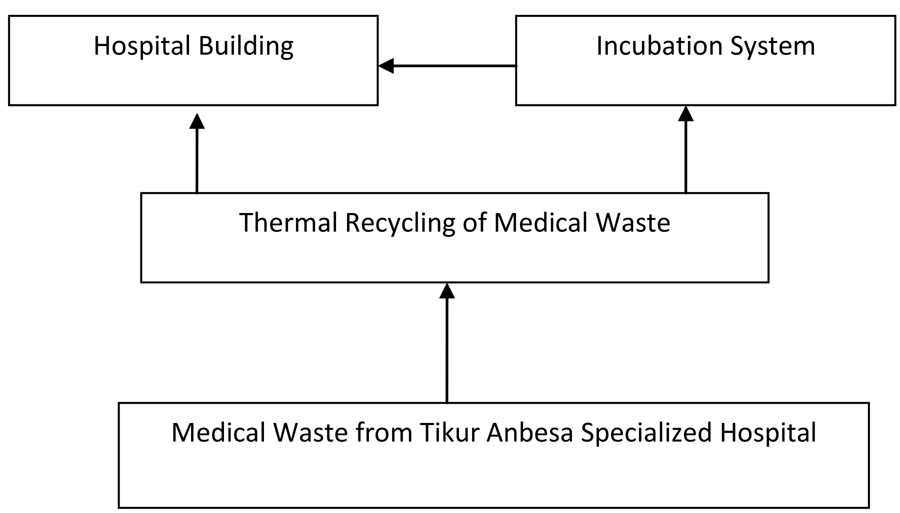


Figure 2: Decision framework for waste-to-energy recovery technology implementation.

2.8. Thermoflex Software

THERMOFLEX is Thermoflow's fully-flexible heat balance and engineering calculation program that allows you to run both design calculation and off-design simulation of a given model. Models are built by connecting individual icons representing one of over 200 different components. THERMOFLEX can also be used in conjunction with one of Thermoflow's application-specific programs (GT PRO, GT MASTER, STEAM PRO, and STEAM MASTER), either by linking the THERMOFLEX model to the application-specific model, or by directly loading the generated plant design into THERMOFLEX for further editing.

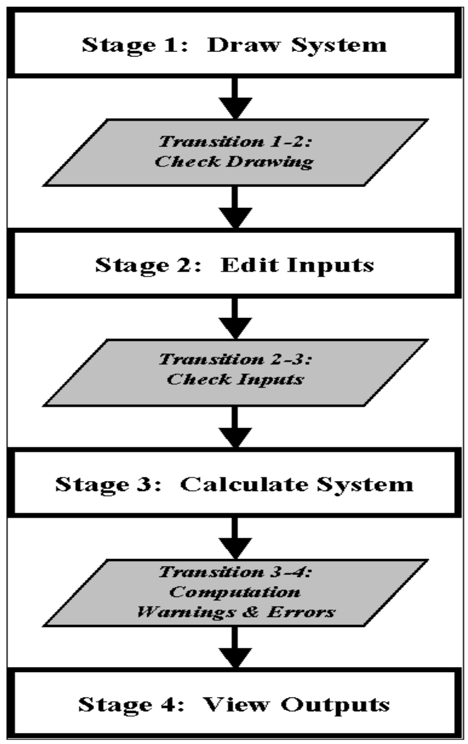


Figure 3: Building a Model – of Termoflex (Thermoflow, Inc., 2002)

This selection process or flow is more general and may differ in each case. In the real life political leaders have power and make their own decision for the implementation of facility either their decision is right or wrong. There are different influencing factors for the selection and finally implementation of feasible waste-to-energy recovery technology like environmental, economic, social, technical and political factors. These factors may have different importance or values according to different country rules and regulation and also depends on the local area requirements. After in-depth analysis of each facility at the end if most feasible technology is selected and successfully implemented may generate numerous befits in the form of job creation, resource conservation, reduce environmental impacts, source of renewable energy, low cost energy, land preservation and lower health impacts etc.

Great furnace

Great furnace is a device used for high-temperature heating. It is a waste treatment process that involves the combustion of organic substances contained in waste materials. Incineration and other high-temperature waste treatment systems are described as thermal treatment. Incineration of waste materials converts the waste into ash, flue gas and heat. The ash is mostly formed by the inorganic constituents of the waste, and may take the form of solid lumps or particulates carried by the flue gas. The flue gases must be cleaned of gaseous and particulate pollutants before they are dispersed into the atmosphere. In some cases, the heat generated by incineration can be used to generate electric power (Thermoflow, Inc., 2002).

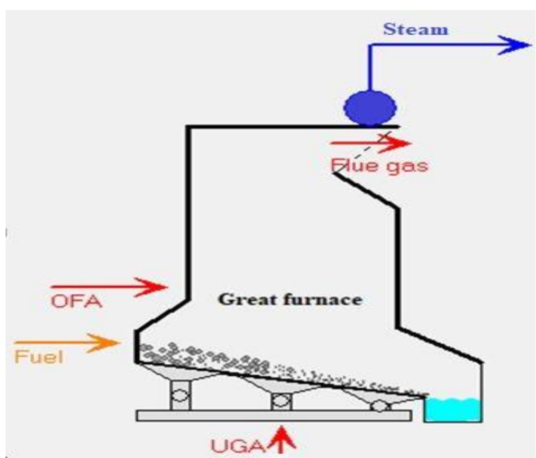


Figure 4: Great furnace source: (Thermoflow, Inc., 2002)

Economizer

Economizers are mechanical devices intended to reduce energy consumption, or to perform useful function such as preheating a fluid. The term economizer is used for other purposes as well. Boiler, power plant, heating, refrigeration, ventilating, and air conditioning uses are discussed in this article. In simple terms, an economizer is a heat exchanger (Thermoflow, Inc., 2002).

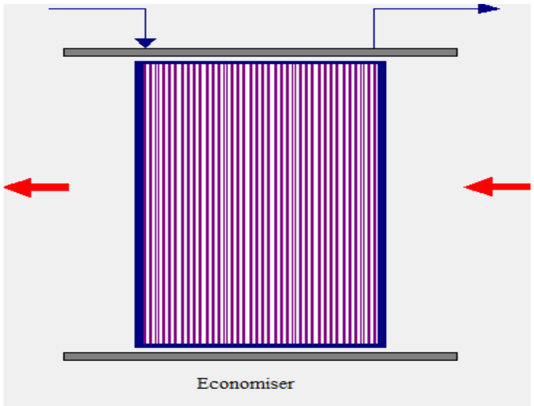


Figure 5: Diagram of Economizer source: (Thermoflow, Inc., 2002)

Fabric Filters

Fabric Filters are air pollution control devices that remove particulate matter from a gas stream by passing the dirty air through a layer of cloth. The particulate matter 1deposits on the cloth surface and the clean air passes through. Of all the air pollution control technologies, fabric filters are the predominant particulate removal device used in industrial processes today (Thermoflow, Inc., 2002).

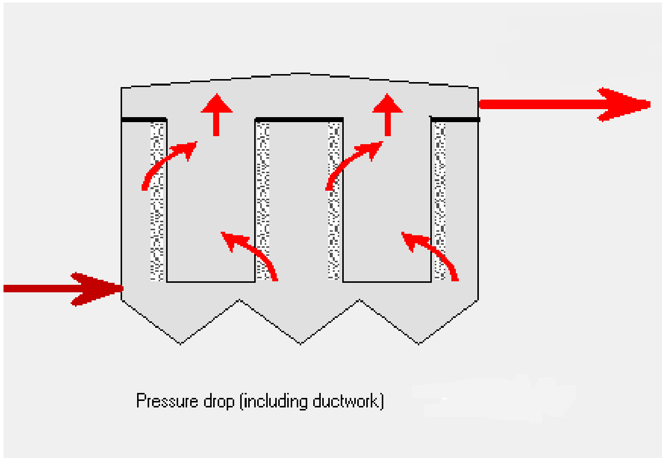


Figure 6: Diagram of fabric filter source: (Thermoflow, Inc., 2002)

Deaerator

A deaerator is a device that is widely used for the removal of oxygen and other dissolved gases from the feed water to steam-generating boilers. In particular, dissolved oxygen in boiler feed waters will cause serious corrosion damage in steam systems by attaching to the walls of metal piping and other metallic equipment and forming oxides. Dissolved carbon dioxide combines with water to form carbonic acid that causes further corrosion. Most deaerators are designed to remove oxygen down to levels of 7 ppb by weight (0.005 cm^3/L) or less as well as essentially eliminating carbon dioxide (Thermoflow, Inc., 2002).

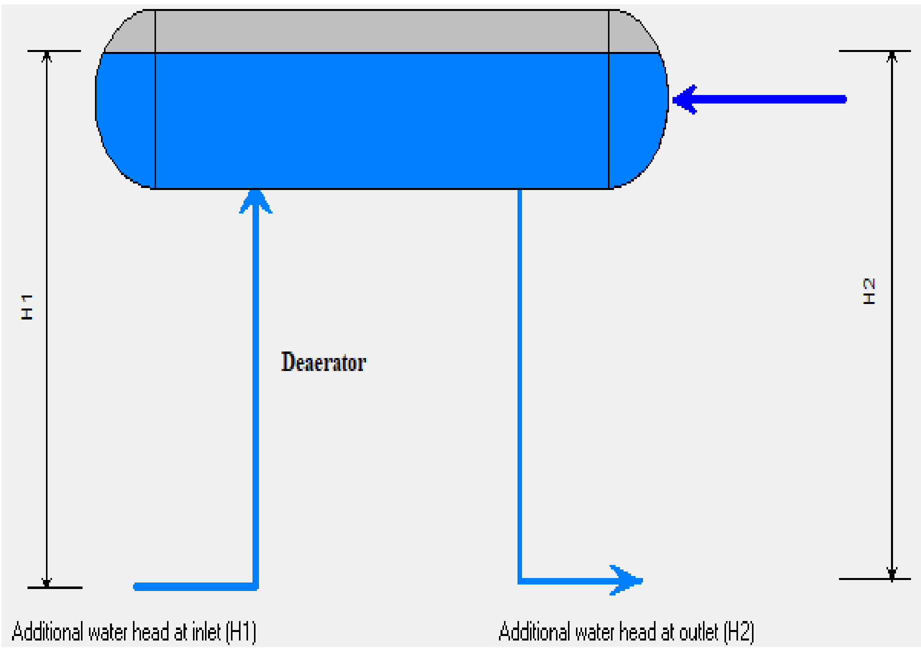


Figure 7: Diagram of deaerator source: (Thermoflow, Inc., 2002)

Turbine

A **turbine generator** is a device that converts mechanical energy into electrical energy. Turbine generators can create electricity using the mechanical energy from many different things: wind, water, steam, fossil fuels, even a human can supply the force needed to produce electricity from a turbine generator.

Whatever it may be, for a turbine generator to function it must collect mechanical energy from an outside force. Turbine generators do not produce energy on their own (Thermoflow, Inc., 2002).

Flue gas treatment

The total air supply to the combustion process is the sum of the primary and secondary air. To secure complete burnout, it is necessary to operate at a certain surplus of air. The excess air passes all the way through the boiler and the flue gas treatment system to the chimney and, depending on the flue gas temperature in the chimney, it represents a loss of energy and hence a loss of thermal efficiency (Thermoflow, Inc., 2002).. The excess air ratio can be reduced, on the primary side, by using a water-cooled grate and on the secondary side by re-circulating a part of the treated flue gas (Flue Gas Recirculation, FGR).It is also of importance whether the entire gas flows through the furnace is counter flow or parallel flow. A proportion (approx. 10% – 20% by volume) of the (usually cleaned) flue-gases is re-circulated, normally after pre-dusting, to replace secondary air feeds in the combustion chamber. This technique is reported to reduce heat losses with the flue-gas and to Increase the process energy efficiency by around 0.75% - 2%.

Table 1: Regulation permissible concentration of pollutions in flue gas in Czech Republic [Andrzej]

Country	Regulation on permissible concentration of pollutants in flue gases
Czech	YES – turbines, engines, boilers
Republic	NO – for burners
	State regulations on permissible emissions from stationary pollution sources into air and on air protection (117/1999Coll)
	NO_x - 350mg/m^3 for gas turbines of < 60000m^3/h
	NO_x - 300mg/m^3 for gas turbines of >= 60000m^3/h
	CO - 100mg/m^3 for turbines
	NO_x - 500mg/m^3 for engines of thermal output of < 0.2MW
	NO_x - 650mg/m^3 for engines of thermal output of > 0.2MW
	NO_x - 200mg/m^3 for boilers of thermal output of > 0.2MW
	CO - 100mg/m^3 for boilers of thermal output of > 0.2MW

Table 2: Regulation permissible concentration of pollutions in flue gas in Hungary [Andrzej]

Hungary	YES – turbines, engines, boilers
	NO – for burners

	State regulations on emissions limits
	For turbines
	KTM 22/1998 – power over 50MW KTM /1998 – power 140 kw-50MW
	NO_x - 150mg/m^3 for new turbines of thermal input 140kw-300MW
	CO - 100mg/m^3 for new turbines of thermal input 140kw-300MW
	NO_x - 500mg/m^3 for 4 strokes gas engines (5% v/v O_2)
	CO - 650mg/m^3 for 4 strokes gas engines (5% v/v O_2)
	NO_x - 350mg/m^3 for boilers (3% v/v O_2)
	CO - 100mg/m^3 for boilers (3% v/v O_2)
	CO - 0.1 % v/v burners (λ=1)

Table 3: Regulation permissible concentration of pollutions in flue gas in Romania and Russian Federation [Andrzej]

Country	Regulation on permissible concentration of pollutants in flue gases
Romania	YES – for CO in flue gases from boilers and burners
	Decree of Ministry of environment protection 462/1993 on permissible emissions of
	NO_x – 350 mg/m^3 for burners CO – 150 mg/m^3 for burners
Russian	Yes - for turbines, engines and boilers
Federation	
	Permissible emission limits are specified in standards and company codes of
	NO_x - 300mg/m^3 for turbines (OCT 29328-92; RD 51-0158623-07-95)
	NO_x - 200mg/m^3 for engines (OCT 24585-81; RD 51-0158623-07-95)
	NO_x - 85 – 275 mg/m^3 for boliers (RD 34.02.305-98)
	CO - 200mg/m^3 for turbines (OCT 29328-92; RD 51-0158623-07-95)
	CO - 200 - 230mg/m^3 for engines (OCT 24585-81; RD 51-0158623-07-95)
	NO_x - 12.4 g/kwh for turbines
	CO - 8.2 g/kwh for turbines

Chapter Three

Materials and Methods

3.1. General Description of Methodology

This study was conduct in selected governmental hospital in Addis Ababa; the hospitals were select judgmental or purposively in order to characterize the solid medical waste in a local context. The hospital was located in the center of Addis Ababa and it is the oldest, largest, most advanced, and comprehensive medical compounds in Ethiopia. Therefore, it was expect that the level of awareness on the proper handling of solid medical waste was higher than other hospitals, health centers, and clinics in the country.

First, Transient observations were done on different ward of the hospital, to ensure reliability during data collection and Selected strategies were employs. Second, the measuring instruments were calibrates third, professionals were selected for data enumerators and supervisor on site during the actual measurements.

Solid medical waste wer collected and measured daily for seven consecutive days from March 4 -11, 2017 G.C were done in the hospital. Data were collect using prepared data entry sheet for the daily measurement of the amount of solid medical waste rate.

Data were collect for 24 hours from each sampling unit in different coded and labeled polyethylene bags. Empty plastic bins of standard colors are black color for general waste, green color for pharmaceutical waste and yellow color used for infectious waste and pathological waste were used to different section of the hospital, for this study only collect general waste.

Waste weighting and recording station was arranged in convenient site within the compound of the hospitals. On the next day, collected wastes in plastic bags were removed every morning and the weight was measured at 12:00 pm and 6:00am (local time) using weighing scale (Baby scale, capacity range 5 kg & model 4 capacity range 200 kg).

3.2. Software's and Equipments

3.2.1. Software's

Thermo flex software was used to estimate the power output.

3.2.2. Bomb calorimeter

A bomb calorimeter is a type of constant-volume calorimeter used in measuring the heat of combustion of a particular reaction. Bomb calorimeters have to withstand the large pressure within the calorimeter as the reaction is being measured. Electrical energy is used to ignite the fuel; as the fuel is burning, it will heat up the surrounding air, which expands and escapes through a tube that leads the air out of the calorimeter. When the air is escaping through the copper tube it will also heat up the water outside the tube. The change in temperature of the water allows for calculating calorie content of the fuel.

Basically, a bomb calorimeter consists of a small cup to contain the sample, oxygen, a stainless steel bomb, water, a stirrer, a thermometer, the Dewar or insulating container (to prevent heat flow from the calorimeter to the surroundings) and ignition circuit connected to the bomb. By using stainless steel for the bomb, the reaction will occur with no volume change observed.

Since there is no heat exchange between the calorimeter and surroundings (Q=0) (adiabatic), no work is performed (W = 0)

Thus, the total internal energy change

$\Delta E_{\text{total}} = Q + W = 0$……………………………………………………………….……….eq 1

Also, total internal energy change

$\Delta E_{total} = \Delta E_{system} + \Delta E_{surounding= 0} \longrightarrow$

$\Delta E_{system} = - \Delta E_{surounding} = \Delta C_v \ \Delta T (constant\ volume \longrightarrow dV = 0)$ …………eq 2

Where C_v is heat capacity

Before the bomb can be used to determine heat of combustion of any compound, it must be calibrated. The value of C_v can be estimated by

$C_{v,calorimeter} = m_{water} . C_{v,water} + m_{steel} . C_{v,steel}$ ……………………………………eq 3

m_{water} and m_{steel} can be measured;

$C_{v,water}$ = 1cal g^{-1} k^{-1} ……………………………………………………………eq 4

$C_{v,steel}$ = - 1cal g^{-1} k^{-1} ……………………………………………………………eq 5

In the laboratory, C_v is determined by running a compound with known heat of combustion value: $C_v = \frac{H_C}{\Delta T}$

Common compounds are benozoic acid (H_C= 6318 cal/g) or p-methyl benzoic acid (H_C= 6957 cal/g).

Temperature (T) is recorded every minute and $\Delta T = T_{final} - T_{initial}$ ………………………eq 6

A small factor contributes to the correction of the total heat of combustion is the fuse wire. Nickel fuse wire is often used and has heat of combustion = 981.2 cal/g

In order to calibrate the bomb, a small amount (~ 1 g) of benzoic acid or p-methyl benzoic acid is weighed. A length of Nickel fuse wire (~10 cm) is weighed both before and after the combustion process. Mass of fuse wire burned $\Delta m = m_{before} - m_{after}$

The combustion of sample (benzoic acid) inside the bomb

$\Delta H_c = \Delta H_{c,benzoic\ acid} . m_{benzoic\ acid} + \Delta H_{c,Ni\ fuse\ wire} . \Delta m_{Ni\ fuse\ wire}$ …………………eq 7

$\Delta H_C = C_v . \Delta T = \frac{\Delta H_C}{\Delta T}$ ……………………………………………………………………eq 8

Once C_v value of the bomb is determined, the bomb is ready to use to calculate heat of combustion of any compounds by $\Delta H_C = C_v . \Delta T$

3.3. Sampling technique

The study area of the hospital was select by using Judgmental or purposively technique, based on patient flow and number of workers

3.4. Study population

This study was conduct in Tikur Anbesa Specialized Hospital were select Judgmental or purposively in order to characterize the solid medical waste in a local context. The hospital is located in the center of Addis Ababa and those are the oldest, largest, most advanced, and comprehensive medical compounds in Ethiopia.

Resources at Tikur Anbesa Specialized Hospital

Table 4: Description of patient flow in Tikur Anbesa Specialized Hospital

Total Beds:	600
Beds Devoted to Cancer Care (at the oncology center):	18
Staff Physicians	201
Nurses	627
Dedicated Oncology Nurses	26
Pathologists	>10
Hematologists	2
Medical oncologists	4
Radiotherapists	4
Pediatric oncologists	1
Specialized surgical oncologists	2
General and specialist surgeons	>30
CT scanners	1
MRI scanners	1
Cobalt radiotherapy units	2

Table 5: Patients seen in Tikur Anbesa Specialized Hospitalin 2010

Total Patients	266,975
Total Outpatients	251,560
Adult Cancer Patients	>2000
Pediatric Cancer Patients	>200

3.5. Sample Techniques and Data Collection

This study was conduct in Tikur Anbesa Specialized hospital were select by purposively sampling technique in order to characterization of solid medical waste and estimation of waste-to-energy conversion in a local context. The hospital is located in the center of Addis Ababa and it is the oldest, largest, most advanced, and comprehensive medical compounds in Ethiopia. Therefore, it was expect that the level of awareness of the importance of the proper handling of solid medical waste was higher than other hospitals, health centers, and clinics in the country.

First Transient observations were done on different department of the hospital. To ensure reliability during data collection, selected strategies was employs, next the measuring instruments were calibrates, and then professionals were selected for data enumerators finally, supervisor on site during the actual measurement.

Samplings were collect for a period of one week to determine the solid medical generation rate and effectiveness of medical waste management practices. To assess the medical waste management in terms of segregation, storage, collection, and treatment observational checklist and key informant interview guide were used

Data were collect for 24 hours from each sampling unit in different coded and labeled polyethylene bags. Empty plastic bins of standard colors are black color for general waste, green color for pharmaceutical waste and yellow color used for infectious waste and pathological waste were used to different section of the hospital, for this study only collect general waste.

Solid medical waste was collected and measured daily for seven consecutive days from March 4 -11, 2017 G.C were done in the hospital. Data were collect using prepared data entry sheet for the daily measurement of the amount of solid medical waste rate.

Waste weighting and recording station was arranged in convenient site within the compound of the hospitals. On the next day, collected wastes in plastic bags were removed every morning and the weight was measured at 3:00 am (local time) using weighing scale (Baby scale, capacity range 15 kg & model 4 capacity range 200 kg).

The frequency of daily new patients and those who had some other health services data were taken from OPD registers and total patients number in monthly and annually were taken from annual reports of hospitals. The number of new OPD was used to calculate the daily waste generation.

Five labeled bags were prepared for sorting wastes by their type during collection as shown in Figure 12 After collection the wastes are dried to avoid decay and bad smells and then each finely shredded for a better homogenized mixing of waste components. The wastes then mixed proportionally and separate in three groups (sample) then crushed the samples as shown in the figure 12 and 13.

Figure 8: Sample preparation of SMW in 5 Kilo university department of wood laboratory

3.6. Waste Characterization

Waste characterization is a method used to determine the types of materials being discarded in a waste stream and in what proportion. Characterization further answers other information like moisture and ash content, fixed carbon and volatile matter present in waste, and elemental composition of the waste.

The mixed and crushed waste sample shown in Figure 13 was given to Ethiopian Geological survey Laboratory for the determination of heating value and proximate analysis determination. Part of this sample also is given to Addis Ababa University; Chemistry Department for ultimate analysis figure 14

Figure 9: Sample to Ethiopian Geological survey Laboratory

Figure 10: Sample to Addis Ababa University; Chemistry Department

3.7. Determination of Calorific Value

The heating value (or energy value or calorific value) of a substance, usually a fuel or food is the amount of heat released during the combustion of a specified amount of it. The calorific value is the total energy released as heat when a substance undergoes complete combustion with oxygen under standard conditions. The chemical reaction is typically a hydrocarbon or other organic molecule reacting with oxygen to form carbon dioxide and water and release heat. It may be expressed with the quantities: energy/mole of fuel, energy/mass of fuel and energy/volume of the fuel.

The calorific value is conventionally measured with a bomb calorimeter. It may also be calculated as the difference between the heat of formation of the products and reactants (though this approach is purely empirical since most heats of formation are calculated from measured heats of combustion). For a fuel of composition $C_cH_hO_oN_n$, the magnitude of the heat of combustion is 418 kJ/mol usually to a good approximation (±3%). The calorific value of all organic compounds has the sign corresponding to an exothermic reaction (negative in the standard chemical convention) because the double bond in molecular oxygen is much weaker than other double bonds or pairs of single bonds, particularly those in the combustion products carbon dioxide and water; conversion of the weak bonds in oxygen to the stronger bonds in carbon dioxide and water releases energy as heat.

The sample is weighted and placed in a digital Bomb calorimeter for lower heating value determination. The digital Bomb calorimeter is then sealed and the waste sample is ignited electrically. The complete combustion of the waste releases heat and it is measured through the temperature change, which is measured by using a digital sensor, of the water bath surrounding the bomb calorimeter. The heat of combustion can be calculated from the resulting rise in temperature. The same step is re-repeated for accurately determining heating value.

3.8. Determination of Proximate Analysis

Thermo-chemical behavior of above discussed waste such as moisture content, ash content, volatile matter and fixed carbon were determined by standard procedures. The moisture content is determined by the loss in weight that occurs when a sample is dried in a laboratory oven at 105 °C for 1 hour. The volatile matter has been determined by involving measurement of weight loss following combustion of about 1g waste in a furnace at 950°C for 6 min. To determine the ash content, the char samples were further heated in a laboratory ash furnace at 750 °C for at least 3hours. The results of the proximate analyses of the waste are shown in Table 11.

Calorific value can be determined experimentally or from theoretical considerations. In laboratory Bomb calorimeter is used where 1g coal is combusted at constant volume and rise in temperature is noted. In terms of % of elements:

Gross calorific value (GCV) = 81%C + 341 (%H - %O/8) + 22%S kcal/kg or…………..eq 9

NCV = 339%C + 1427 (%H - %O/8) + 92%S kJ/kg……………………………..……eq 10

Net calorific value (NCV) = GCV – Heat of vaporization of water…………………..…..eq 11

NCV = GCV – Heat of vaporization of water

NCV = GCV – 5.84(9%H + %M) kcal/kg ……………………………………….…..eq 12

3.9. Determination of Ultimate Analysis

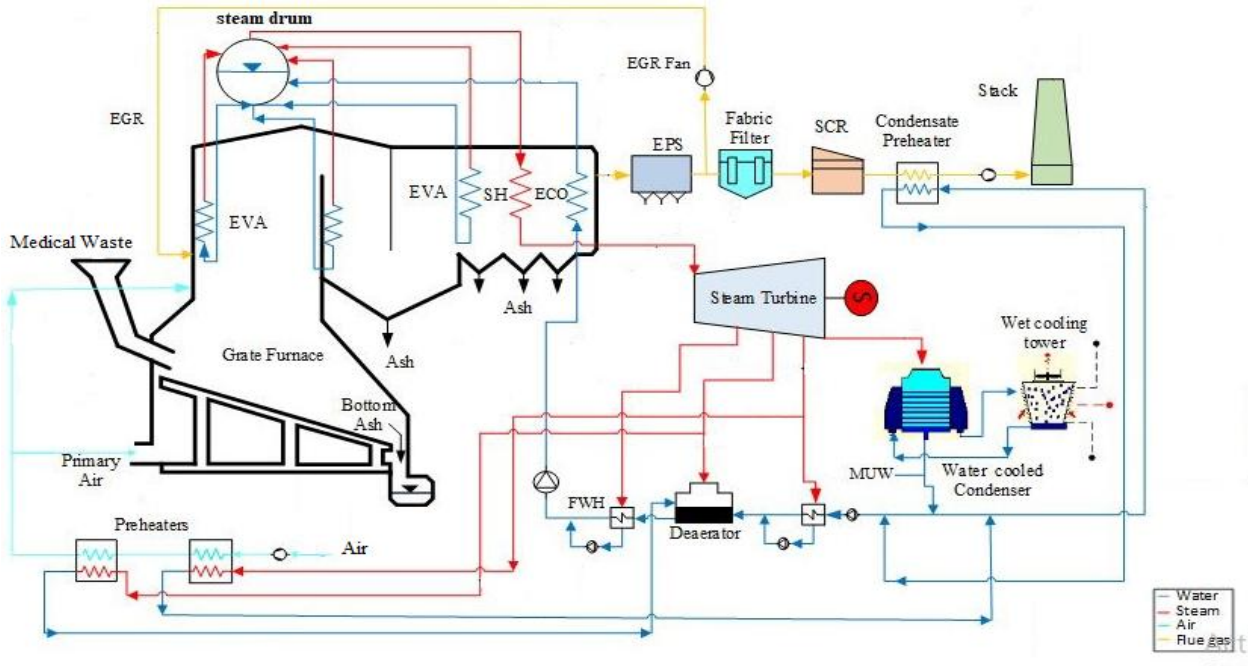
Ultimate analysis is an important aspect to be applied to the theoretical calculation of combustion and heating value. It comprises the analysis of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), and sulfur (S) represented in weight percent on a dry basis (wt. % on a dry basis). Samples analyses proved that carbon became the most dominant component, followed by oxygen. The average percentage of hydrogen and nitrogen contents in the samples was lower than 10%. Hydrogen and oxygen are contained in MSW not as gasses, but they are bound by the other substances. Oxygen is eight times lighter than hydrogen. Hence, more oxygen is required to burn hydrogen to form H_2O. Plastic has the highest carbon content (80% wt.), while the lowest carbon content goes to animal bones (33.84%wt.). Wood mostly contains oxygen (44.43wt. %), whereas plastic has the lowest oxygen content (3.98%wt.). Meanwhile, the highest H is contained in plastic. In a combustion process, C and H are oxidized by the exothermic reaction to form of CO_2 and H_2O

3.10. Thermodynamic Modelling of WTE Plant

The thermodynamic model of WTE plant considered in this thesis aim to discuss major plant components working principle and mathematical model used for the analysis. The major plant components include heat exchangers, evaporator, super heater, economizer, turbine, and pumps.

3.11. Plant Layout

The plant layout is for a mass-burn incinerator with energy recovery for the sole production of electricity consuming 1391.54kg/day of waste, which corresponds to approximately 0.73MW of thermal input, is combusted over combustion line with a Rankin cycle. The steam turbine generates approximately 0.73 MW of net electric power at gross electric efficiency of 21.78%. In order to preheat the primary and secondary combustion air, steam is extracted from the steam cycle at a pressure of 1.1 and 1.07 bars. Part of steam extracted at 1.1 and 1.07 bar is used for de-aerator and to preheat the feed water heater respectively. The steam, which enters into the steam cycle, is superheated at a pressure of 40bar/ 400°C. The nominal steam production of the line is 13.53ton/h. The exhaust steam from the Rankin cycle is condensed by using a water-cooled condenser with a nominal condensation pressure of 0.07bar. The flue gases leaving the boiler at 178.9 °C enter a flue gas treatment system that includes electrostatic precipitator (ESP); reactor with the injection of sodium bicarbonate and active carbon and fabric filter. In order to control the NO_x, Selective Non Catalytic Reduction (SNCR) system is used with the injection of Ammonia in the flue gas at a temperature of around 1000°C. The reducing reagent, ammonia or urea, selectively reacts with nitrogen oxides that exist in the flue gas at high temperature and converts into harmless molecular nitrogen and water vapour without using a catalyst. In the last part of the flue gas treatment system line, a small portion of heat is recovered for condensate and feed-water preheating. This final heat exchanger is also used to maintain the stack temperature at 135°C. The plant process flow is indicated in Figure 15.



Figures 11: Mass-burn incinerator of Thermoflex software

3.12. Assumptions for Model Plant Simulation

All SSWTE plants in this study will operate for 330 days per annum, two shifts per day (16hr).

Table 6: Main assumptions adopted for plant simulations

Reference conditions for model plant	Assumption of simulation
Ambient temperature (°C)	15
Ambient pressure (bar)	1.01325
Relative humidity (%)	60
Plant	
Treated waste (t/y)	359,576.1
Equivalent working hour (h/y)	5840
Waste flow rate (kg/s)	0.217
Rated thermal input, MW_{LHV} kj/kg	18031

Combustor	
Primary air preheating temperature	60
Secondary air preheating temperature	150
Thermal losses, % LHV	2.5
O_2 at boiler exit, % Vol. dry	6.0
Losses of unburnt carbon, % LHV	1.65
% of excess air supplied	50
Boiler	
Flue gas temp. at boiler exit (°C)	108
Thermal losses, % of exchanged power	1.0
Steam cycle	
Steam Temperature (°C) at the turbine	400
Steam pressure (bar) at the turbine inlet	40
De-aerator pressure (bar)	1.3
Steam bleeding for primary and secondary	1.3 and 0.8
Condensation pressure (bar)	0.07
O_2 at Stack, % vd	6.0
Flue gas recirculates (% mass)	55
Stack temperature (°C)	135

3.13. Thermodynamic Models

Here mathematical model of particular elements of the model plant: heat exchanger, steam turbine, condenser and a circulation pump was discussed. Assumed is internal irreversibility in the turbine and pump.

Main parts of thermoflex software

3.13.1. Heat exchangers

Heat exchangers are devices that transfer heat between two fluids. They can transfer heat between a liquid and gas. These devices are used like air conditioning, gas turbine etc. It is assumed that the heat exchangers are well-insulated so that all the heat transfer is between the flue gas and the water. In keeping with overall assumptions, it is also assumed that the flow is steady, and that the differences in entering and leaving potential energy and kinetic energy are negligible. The balance of rates of heat transferred in the heat exchanger (including the deaerator) can be written in the form

$$\dot{Q}_{in} = \dot{Q}_{loss} - \dot{Q}_{out} \quad \text{……………………………………………………………..eq 13}$$

Where $\dot{Q}_{in}$ - rate of heat supplied to heat exchanger. $\dot{Q}_{out}$ – rate of heat received from heat exchanger. $\dot{Q}_{loss}$- rate of heat lost to surroundings. For the case of the open-feed water heat exchanger

$$\dot{m}_s h_s + \dot{m}_{con} h_{con} + \dot{m}_w h_1 = \dot{Q}_{loss} + (\dot{m}_{con} + \dot{m}_s) h_m + \dot{m}_w h_2 \text{…………………..eq 14}$$

Where: $\dot{m}_{con}$ – mass flow rate of condensate, h_s – steam enthalpy, h_{con} –condensate enthalpy, h_m – enthalpy of the condensate-steam mixture, h_1 – water enthalpy at inlet to heat exchanger, h_2 – water enthalpy at outlet from heat exchanger. Therefore the efficiency of the fed water heat exchanger can be expressed by,

$$\eta_{HE} = \frac{\dot{Q}_{out}}{\dot{Q}_{in}} = \frac{\dot{m}_w (h_2 - h_1)}{\dot{m}_s (h_s - h_m) + \dot{m}_{con} (h_{con} - h_m)} \text{…………………………………..eq 15}$$

The heat transfer $\dot{Q}$ is expressed as

$$\dot{Q} = U \times A \times LMTD = \frac{LMTD}{\frac{1}{U \times A}} = \frac{\frac{\Delta T_{hot} - \Delta T_{cold}}{\ln\left(\frac{\Delta T_{hot}}{\Delta T_{cold}}\right)}}{R_t} \text{…………………………………………..eq 16}$$

$$= \frac{\frac{\Delta T_{hot} - \Delta T_{cold}}{\ln\left(\frac{\Delta T_{hot}}{\Delta T_{cold}}\right)}}{\frac{1}{h_{con,in} \times A_{in}} + \frac{R_{fou,in}}{A_{in}} + \frac{\ln\left(\frac{D_{Out}}{D_{in}}\right)}{A_{out}} + \frac{R_{fou,out}}{A_{out}} + \frac{1}{h_{con,out} \times A_{out}}} \text{…………………eq 17}$$

Where U is the overall heat transfer coefficient, A is the heat transfer area that is constant, it is determined during on-design conditions and LMTD is the log mean temperature difference between hot and cold stream.

The pressure drop ($\Delta\mathbf{P}$) in the heat exchangers is proportional to the square of the mass flow rate. It can be expressed in terms of mass flow rate by assuming a constant pressure drop coefficient $\mathbf{k_i}$ which calculated during at design conditions, according to Darcy equation for turbulent flows and by assuming negligible variations of friction factor.

$\Delta\mathbf{P} = \mathbf{k_i} \times \dot{\mathbf{m}}^{\mathbf{2}}$……………………………………………………………………...…..eq 18

3.13.2. Steam turbine

Maximum generator output is directly affected by changes in the efficiencies of the various turbine sections and changes in the flow capacity of the first three or four stages of the high-pressure turbine. Changes in the flow capacity of following stages may indicate a physical change in the steam path and consequential effects on local steam path efficiency. A change in the flow capacity of the turbine or the flow capacity of a particular turbine stage is reflected in the stage pressure, temperature, and flow relationship. For all turbine stages except the first and last stage, the stage pressure ratios are essentially constant and the basic flow equation simplifies to:

$\boldsymbol{M} = \boldsymbol{K}\,\boldsymbol{A}\,\boldsymbol{C_q}\sqrt{\frac{\boldsymbol{P}}{\boldsymbol{v}}}$ ………………………………………..……………….. eq 19

Where: M - Flow to the following stage, K - A constant, A - Nozzle area, $\boldsymbol{C_q}$ - Coefficient of discharge, P - Inlet stage pressure, v - Specific volume at stage inlet.

Gross electric power of the power unit has been determined on the basis of electric power produced by successive turbine stages, $\boldsymbol{N_{el\_T}}$, which can be written as,

$\boldsymbol{N_{el\_gross}} = \sum \boldsymbol{N_{el\_T}}$ ………………………………………………………………. Eq 20

Efficiency of gross production of electricity has been defined as a ratio of electric power generated by the unit, $\boldsymbol{N_{el\_gross}}$, to the rate of heat of chemical energy in the fuel which described as,

$$\eta_{N_{el\_gross}} = \frac{N_{el\_gross}}{\dot{m}_{fuel}\ LHV} \quad \text{……………………………………………………….……………. Eq 21}$$

3.13.3. Feed pump

The electric power consumed by the pump, N_{el_pump} , for increasing the working fluid pressure is determined using the pump internal efficiency η_{i_pump} , mechanical efficiency, η_{m_pump} , efficiency of conversion of electric energy into mechanical one, η_{el_me} and pressure P_2, which must be ensured by the pump. The liquid at the inlet to the pump has a given temperature T_1 , pressure $P_1$and mass flow rate $\dot{m}_w$. The process of pressure increase, referring enthalpy - entropy relations, in a real pumping from P_1 to P_2, as compared to isentropic pumping, characterized by the pump internal efficiency defined as,

$$\eta_{i_{pump}} = \frac{h_{2s} - h_1}{h_2 - h_1} \quad \text{…………………………………………………….………. Eq 22}$$

Where: h_1, h_2, h_{2s} – enthalpy of fluid in real process (1 - 2) and isentropic process (1 - 2s).

The consumed electric power by the pump, N_{el_pump} , is determined from relation

$$N_{el\_pump} = \frac{\dot{m}_w (h_2 - h_1)}{\eta_{el\_me}\ \eta_{m\_pump}} \quad \text{……………………………………………..……. Eq 23}$$

Chapter Four

Results and discussion

4.1. Generation rate of solid medical waste

The daily distribution of solid medical waste generation rate was highest in week days and less in weekend days. This variation happens due to flow of patients special OPD has high contribution because in weekend days the hospital does not give service for OPD patient unless emergency cases are come up.

The results indicate that in table 7 different categories of waste are not equally generated as some categories such as food waste has high rate of generation while others such as clothes waste.

Table 7: Mass distribution of SMW categories

Waste Category	%Generation rate of SMW
Food	68.26
Plastic	14.68
Paper	12.84
Wood	2.99
Clothe	1.23
Total	100

The total waste per day in this hospital is 1391.57kg/day; the estimation of generation waste in annually is 507,923.57kg/year or 507.9tonnes/year.

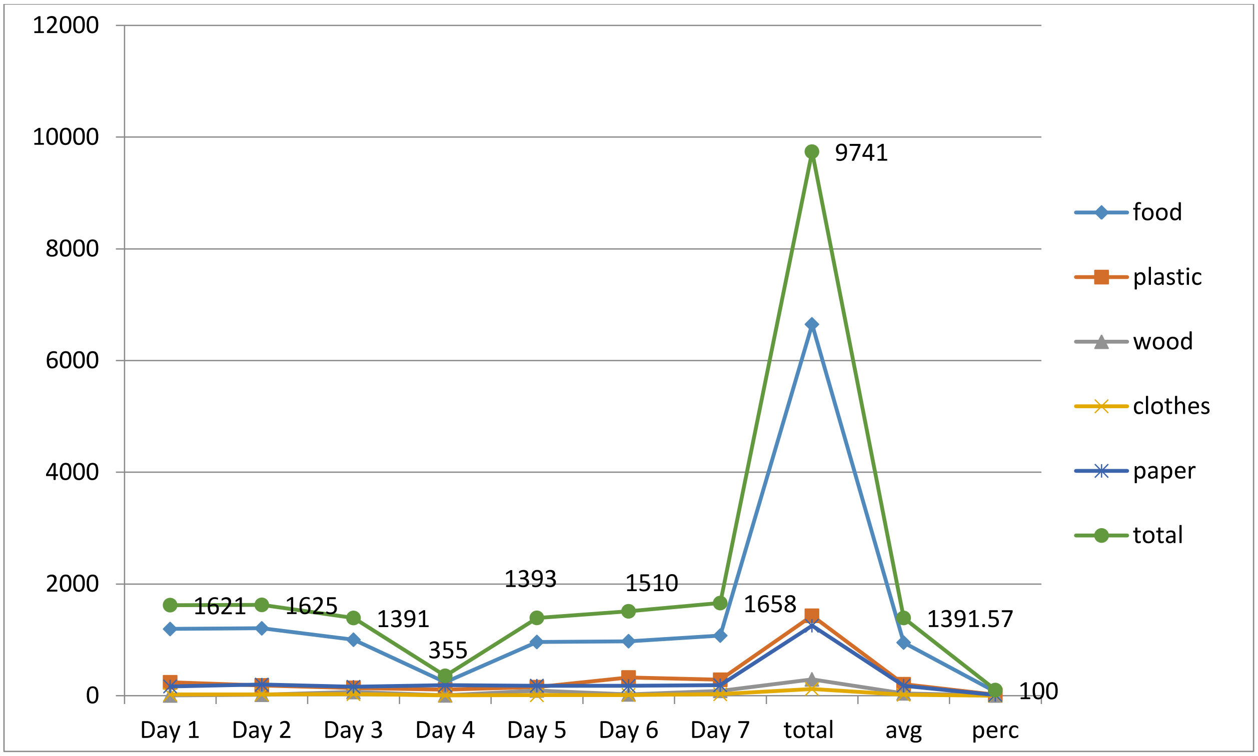


Figure 12: generation rate of solid medical waste in Tikur Anbesa Specialized Teaching Hospital

Patient loads was one of the factor that affect the generation rate of medical waste in the study hospitals, patient number is directly proportional to the generation rate of medical waste.

In order to have a better understanding of the SMW that is being disposed of, below are listed the types of categorizations that can be found in solid medical waste:

- ✓ Non-infectious waste
  - Food waste
  - Paper waste
  - Clothe waste
  - Plastic waste
  - Wood waste

4.2. Assessment of medical waste management practice in the hospital

In Ethiopia, there is no specific medical waste management legislation. However, there are policies and legislations with provisions that may offer a legal frame for the management of medical waste (Ministry of health, 2008). The Ethiopia Environmental Pollution Control Proclamation, No. 300 of 2002, after defining hazardous waste as an unwanted material that is believed to be deleterious to human safety or health or the environment pronounces the following prohibitions and restrictions in its management.

"No person shall pollute or cause any other person to pollute the environment by violating the relevant environmental standards (Article 3-sub article 1)." Concerning the management of hazardous waste, it states that the generation, keeping, storage, transportation, treatment or disposal of any hazardous waste without a permit from the Environmental Protection Authority or the respective Regional Environmental Agency is prohibited (Proclamation, No. 300/2002).

The Ethiopia Public Health Proclamation No.2000 pronounces the following prohibitions and restrictions about medical waste any solid, liquid and other wastes generated from hospitals should be handled with special care and their disposal procedures should meet the standards set by the public health authorities. The proclamation neither provided a clear definition of the various categories of MW nor did it indicate the legal obligations that MW producers have with regard to segregation, safe handling, treatment and disposal. In addition, it did not indicate specifications for record keeping and reporting, and inspection systems for enforcement of the law (Proclamation, No. 12/2000). The Environmental Impact Assessment Proclamation no. 299/2002 requires proponents to undertake Environmental Impact Assessment (EIA) for those projects considered to have significant environmental impacts and listed as such in directives issued pursuant to this proclamation. According to the EIA guideline issued by the Federal Environmental Protection Authority (FEPA), large hospitals waste incineration facilities, chemical treatment facilities and landfills for toxic, hazardous and dangerous wastes are among the list of projects considered to have adverse and significant environmental impacts and hence require full environmental impact assessment (FEPA, 2000).

To investigate the overall practice of medical waste management used both semi structured questionnaire and observational checklist adapted from WHO medical waste management rapid assessment tools (Lars *et. al*., 2000). Both interviews and observations were conducted by principal investigators from May - June 2017 the interview was administered involving hospital staff (administrators, medical directors, and heads of some departments; for example, Pharmacy, laboratory, pathology, surgery, environmental health and workers directly involved in waste handling). The main questions were regarding segregation, collection, transportation, storage, treatment, disposal, waste re-cycling and re-use, internal policies and administration, training, and budget for medical waste management.

The hospitals had National Medical Waste Management Guideline prepared by FMOH in 2008; but not use it properly, except some department; during transportation of collected MW from the source to the incinerator were mixed wastes used one plastic bin. The wastes were scattered on the surrounding treatment and disposal sites due to the use of sub-standard waste containers. This will also contribute to the risk of infections for healthcare providers, patients, visitors and the neighboring community. After disposal in the incinerator area, the general waste of healthcare were stays some days and pollute the environment.

4.2.1. Segregation practice

In the study hospital, segregation of sharp waste using the safety box was practiced. Placentas and blood stained cotton pads were kept in separate containers; the use of waste containers with only color code at the point of generation was implemented in the hospital. Even though in some department was observed some problem in segregation practices Overall, the practice of medical waste segregation was found to be moderate limited.

Figure 13: waste containers with a color code in Black Lion Hospital

4.2.2. Collection and transportation of the hospital

There was no structured collection and transportation system for general and hazardous waste they were used closed plastic container (capacity of 50 litters) to collect and transport mixed. Only sharps and pathological wastes were collected and transported separately.

Medical waste was collected and transported to incineration facilities by using wheeled cart twice a day in the morning before 12:00am and in the noon day after 6:00 am by cleaning agency and visited by the supervisor of environmental health department.

Figure 14: waste collection system in Black Lion Hospital

4.2.3. Medical waste treatment and disposal practice

Black lion specialized teaching hospitals, was used several methods for infectious and sharp waste treatment, depending on the type of waste material generated. These treatment methods include one of the following option or combination of option: steam sterilization, incineration, thermal inactivation, and gas vapor sterilization, and chemical disinfection, sterilization by irradiation or electromagnetic radiation. After treatment the wastes or their ashes should disposed of by discharge into sanitary sewer systems.

The study conducted in developing countries reviled that the commonest method of medical waste treatment was done by poor design and construction incinerators have low combustion capacity (Israel Deneke *et.al*., 2011).

During MW incineration significantly produced high smoke emission in the hospital. The partial burned medical waste was disposed in an open pit. In addition to incinerators, the hospitals had an open hand dug pit in its backyard that was used for the direct dumping and open burning of medical wastes.

Figure 15: medical waste treatment type using chemical disinfection in Black Lion Hospital

Figure 16, medical waste treatment type using steam sterilization and autoclave in Black Lion Hospital

Figure 17, medical waste treatment type using incineration in Black Lion Hospital

4.3. Incineration Plant Modeling

The Waste to energy program is a supporting tool for technological processes simulation [Poma *et al.*, 2010]. Although it was originally created for waste to energy plants simulation, it could also be utilized for modeling of various technological applications. The software was developed in thermoflax and computations use sequential-modular approach (calculations move from one computational node to another until parameters of all units are evaluated). It provides energy and material balances of modeled units. The program enables an easy extension of new technological blocks and streams, which makes this software very versatile. Source code of waste to energy is designed in the way that the addition consists of few operations.

4.3.1. Model Creation

The model creation of a proposed waste to energy plant in the software is presented in Figure 22. The information and values used in the model were taken from a proposed modern design SMW incinerator for energy. The model was created to predict waste to energy plant capacity and annual energy production. In addition, the presented model provides the simulation of thermal stage, where the waste combustion and after-burning processes take place, and heat recovery block, where the heat contained in flue gas is utilized for the production of superheated steam.

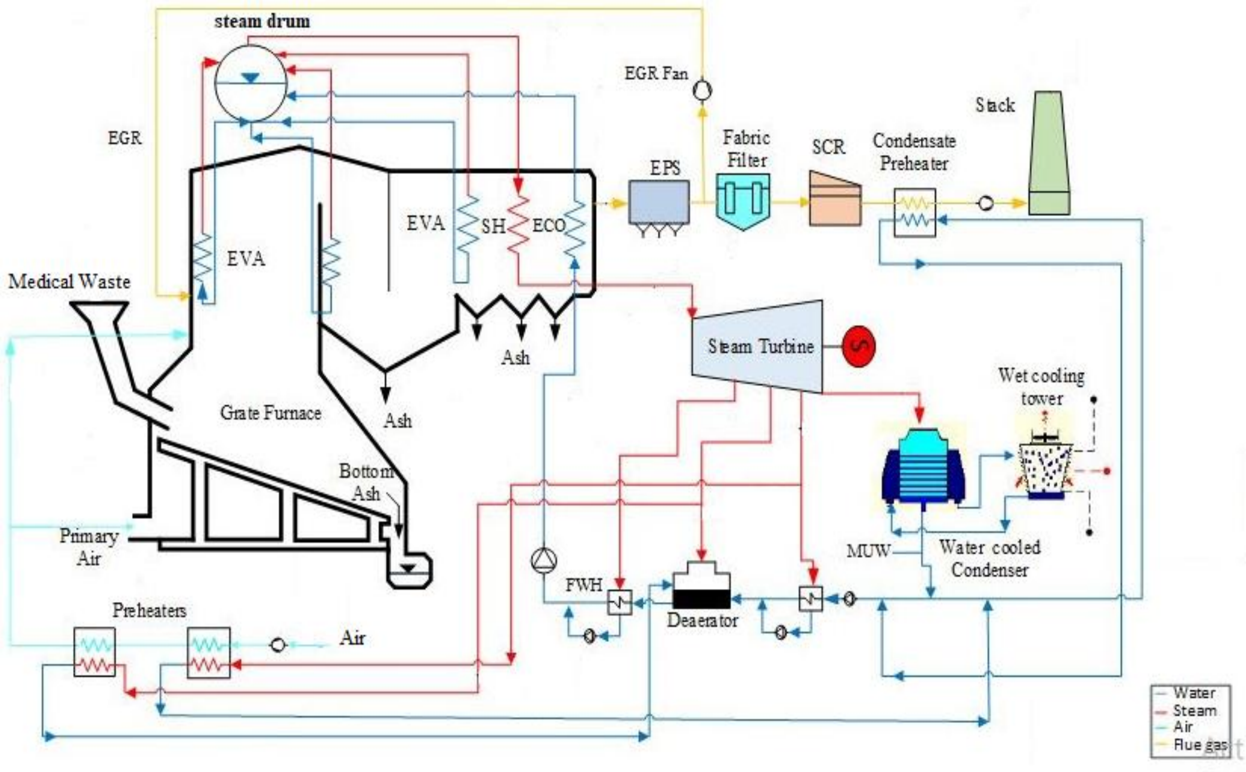


Figure 18: Schematic Diagram of Proposed Incineration Power Plant in the WTE Software

4.3.2. Input Parameters for the Simulation Model

Data on quantity, physical, and chemical characteristics of solid medical waste is important in approaching the design of a waste to energy facility. The quantity of the waste is one of the important input parameters for estimating the electrical energy generation from the facility and is given in Table 8. The average generation of solid medical waste in the hospital for the year 2017, which totaled 507.9 tons per year, was used in the model.

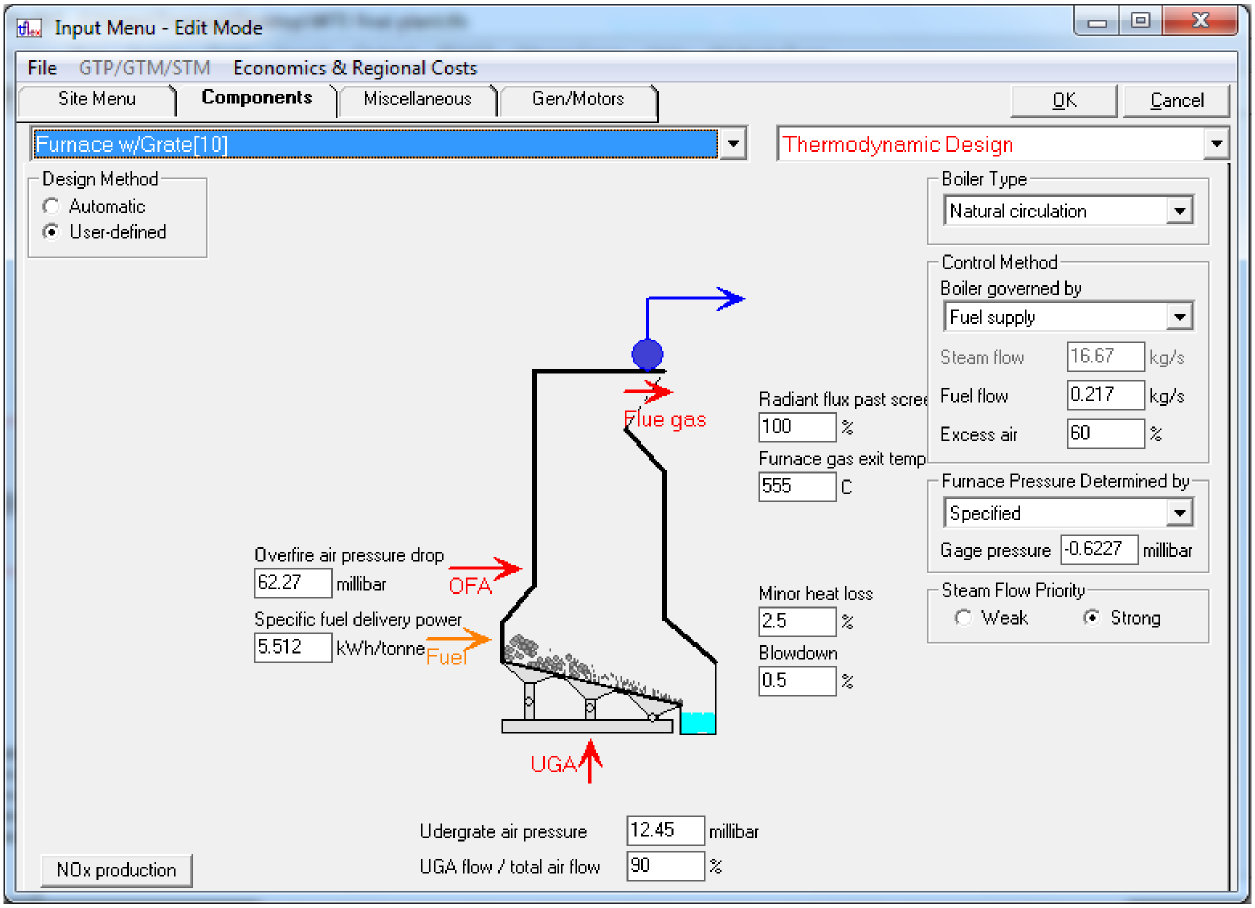


Figure 19, input for grate furnace

The proximate analysis were done in Ethiopian geological survey laboratory

Field no.	Lab no.	Moisture %	Volatile matter %	Fixed carbon %	Ash %	Calorific value %
MWT-01	1270/17	6.75	73.68	11.88	7.69	4224.18
MWT-02	1271/17	6.68	73.19	11.85	7.85	4259.22
MWT-03	1272/17	7.03	71.50	11.74	9.73	4463.63
MWT-03	1272/17dup	6.52	72.73	11.76	8.99	4437.46
AVAREGE		6.745	72.775	11.8075	8.565	4346.1225

Table 8: Result of proximate analysis and calorific value from geological survey laboratory

Ultimate analyses (elemental analysis, C, H, N, S, and O) were done in Addis Ababa University, natural science college Department of Chemistry.

Sample Code	N (%)	C (%)	H (%)	S (%)
MWT1a	0.480981	40.78345	5.856054	0
MWT1b	0.541268	45.75863	6.564746	0
MWT2a	0.468612	44.46656	6.20463	0
MWT2b	0.541614	46.88259	6.17576	0
MWT3a	1.057207	44.20624	6.669926	0
MWT3b	0.920273	44.24462	6.640183	0
AVERAGE	0.67	44.39	6.35	0

Table 9: Result of Ultimate analysis from AAU of college of natural science chemistry department

Oxygen content was calculated from equation shown below

$$O = 100 - (C + H + N + Ash + Moisture) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eq24$$

S were omitted since its amount was zero and neglected for ease of calculations.

$$O = 100 - (44.39 + 6.35 + 0.67 + 8.565 + 6.745 = 33.28$$

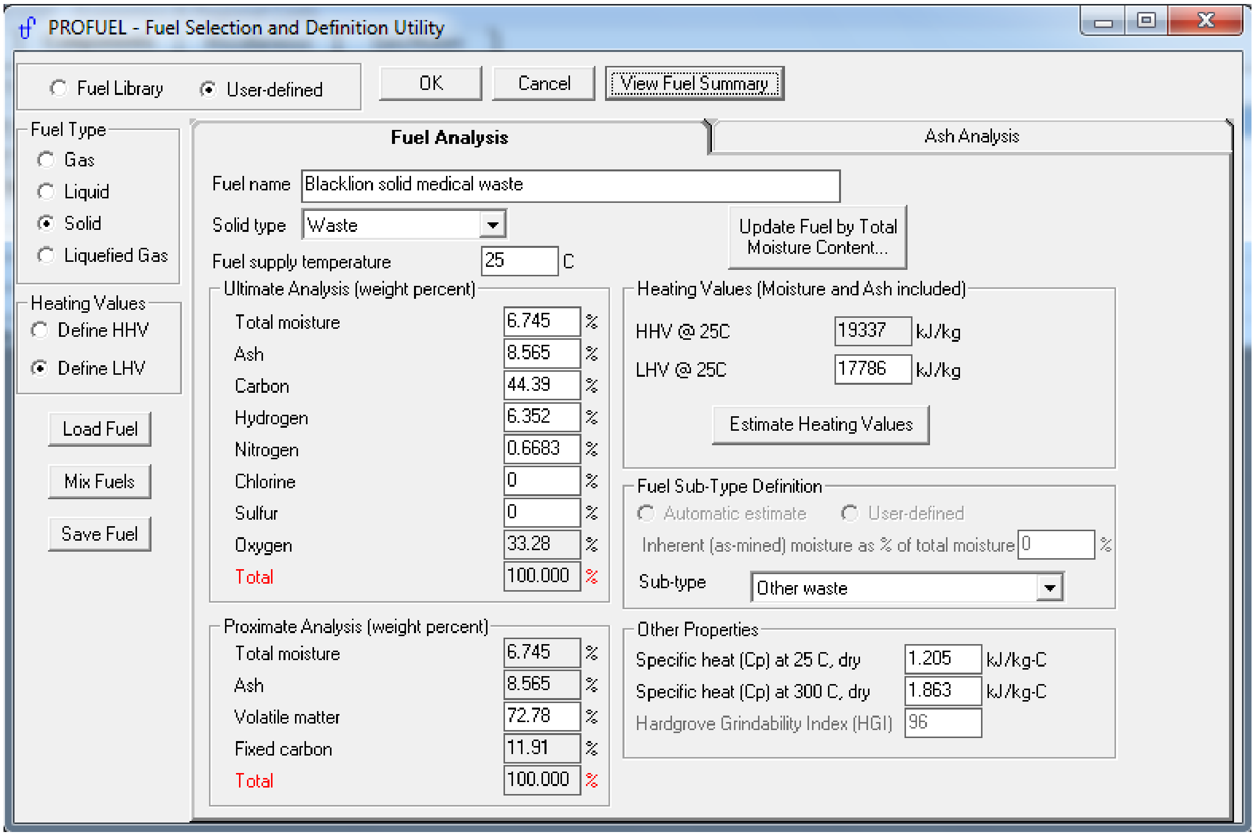


Figure 20: Data input in the thermo flex software simulation

4.4. Waste to energy technology

4.4.1. Estimation electric generation

WTE reduces the volume of the SMW by approximately 90%, leaving the remaining 10% as ash. This ash can is reused in construction applications like range. In the U.S., less than 5% of this ash is used beneficially because of the lack of national standards regarding the beneficial use of the ash. On the other hand, European countries, or even islands such as Bermuda reuse over 70% of the ash in construction applications.

Waste-To-Energy: The best MSW operation to dispose of the remaining waste, after recycling and composting, is the combustion of the waste with energy recovery or waste-to-energy (WTE). WTE plants burn MSW under controlled conditions and generate steam that is used in a turbine to generate electricity. Typically, a WTE facility generates between 500 to 700 kWh per ton of MSW combusted.

4.4.2. Model Validation

Validation is concerned to confirm or establish the truthfulness or soundness of determining whether the model is an accurate representation of the system under study. The conceptual model of a process is a formal definition of the system under consideration in logical or mathematical form, typically comprising the underlying theoretical equations.

Data from literature set under Table 12 is used for validation. The consolidated data from this table will referred as model test data. The main parameters under these consolidated data are: steam data (355bar/340C), fuel input (1391.54kg/day), and thermal input (15.09 MW). When the model test data inserted in to the Thermoflex model and simulated, it is observed that the electric power generated the gross power was 840.6 kw and net power was 731.9 kw.

Reference conditions		Result
Primary air heat temperature	60C	103.8C
Secondary air heat temperature	150C	103.8C
Fuel gas temperature	180C	180C
Steam production		2799.82kj/kg
Steam temperature at turbine inlet	251.5C	251.5C
Steam pressure at turbine inlet	40.8bar	40.8bar
Ash	0.010kg/s	0.002kg/s
Condenser pressure	0.305bar	0.305bar
Electric power generated (Net)		731.9Kw/h

Table 10: Comparison of model test and simulation data

4.4.3. Result of Simulation

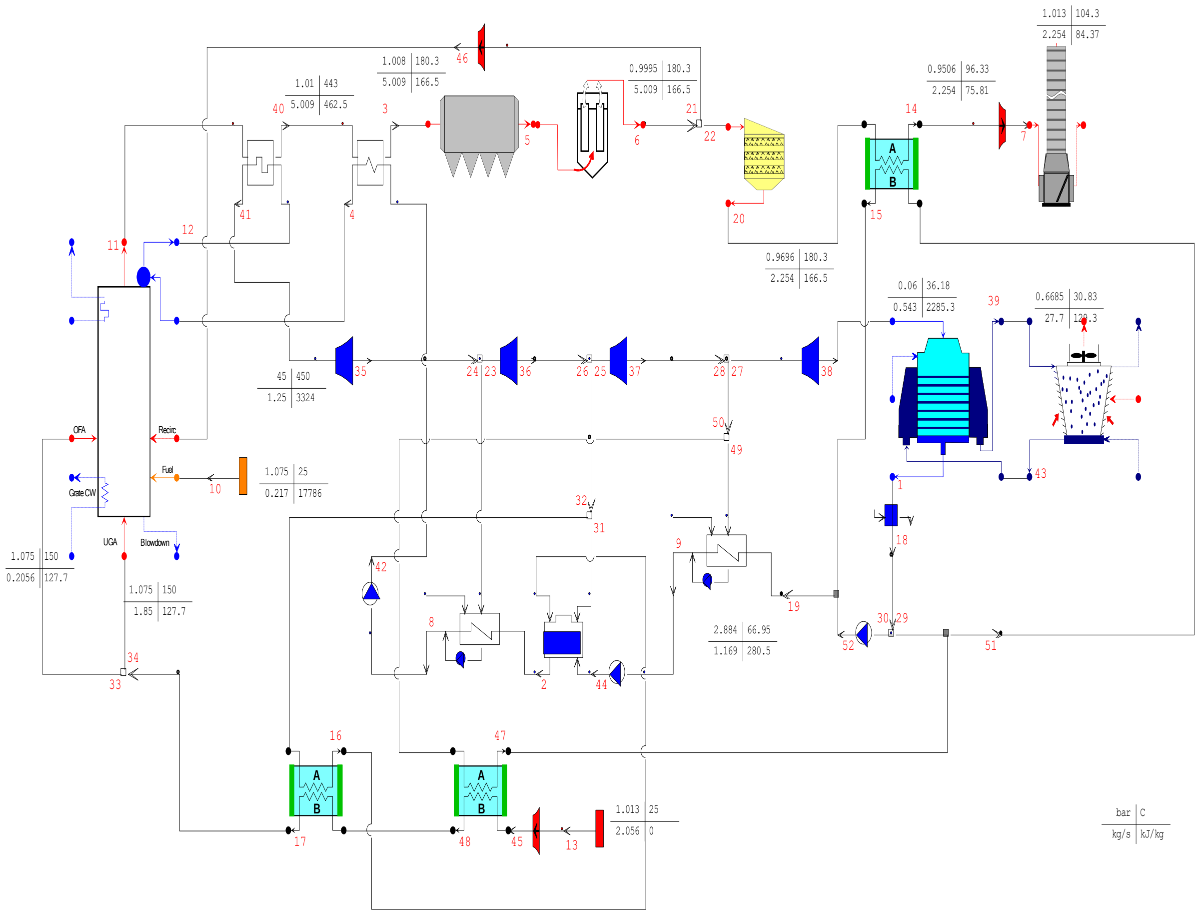
After the model is validated, then it further simulated with desired assumed operating parameters and according to laboratory result the simulation result listed under Table 9 only common parameters are listed in the table.

Results and Analysis

Steam turbines obtained from waste to energy software simulation. It is clear from the results that the output power and the annual energy generation increase by both the waste quantity and the energy content of the waste composition.

Table 11: Result of simulation

Reference conditions for model plant		Simulation Result
Primary air preheating temperature(°C)	60	60
Secondary air preheating temperature(°C)	150	103.8
Flue gas temp at boiler exit (°C)	180	178.9
Turbine temp at boiler exit (°C)	450	
Steam production (kg/s)	--	3.76
Stack temperature (°C)	135	135
Gross power generated (kW)	--	**840.6**
Net electric power generated (kW)	--	**731.9**
Gross electric efficiency (%)	--	**21.78**
Net electric efficiency (%)	--	**18.96**



Ambient temperature	15	C
Gross power	840.6	kW
Gross electric efficiency (LHV)	21.78	%
Net power	731.9	kW
Net electric efficiency (LHV)	18.96	%

Figure 21: simulation result diagram

Plant summary

Table 12: Result of simulation plant summary

Parameters	Unit	Out put
Ambient pressure	bar	1.013
Ambient temperature	C	15
Ambient RH	%	60
Ambient wet bulb temperature	C	10.82
Gross power	kW	8406
Gross electric efficiency (LHV)	%	21.78
Gross heat rate(LHV)	kJ/kWh	16530
Net power	kW	731.9
Net electric efficiency (LHV)	%	18.96
Net heat rate (LHV)	kJ/kWh	18983
Net fuel input (LHV)	kW	3860
Net process out put	kW	0
CHP efficiency	%	18.96
PURPA efficiency	%	18.96
Plant auxiliary	kW	108.7
Net electric efficiency (HHV)	%	17.44
Net heat rate(HHV)	kJ/kWh	20639
Net fuel input(HHV)	kW	4196
Energy chargeable to power	kW	3860
Electric efficiency or chargeable	%	18.96
Water consumption	Kg/s	1037
Water discharge	Kg/s	0.09616

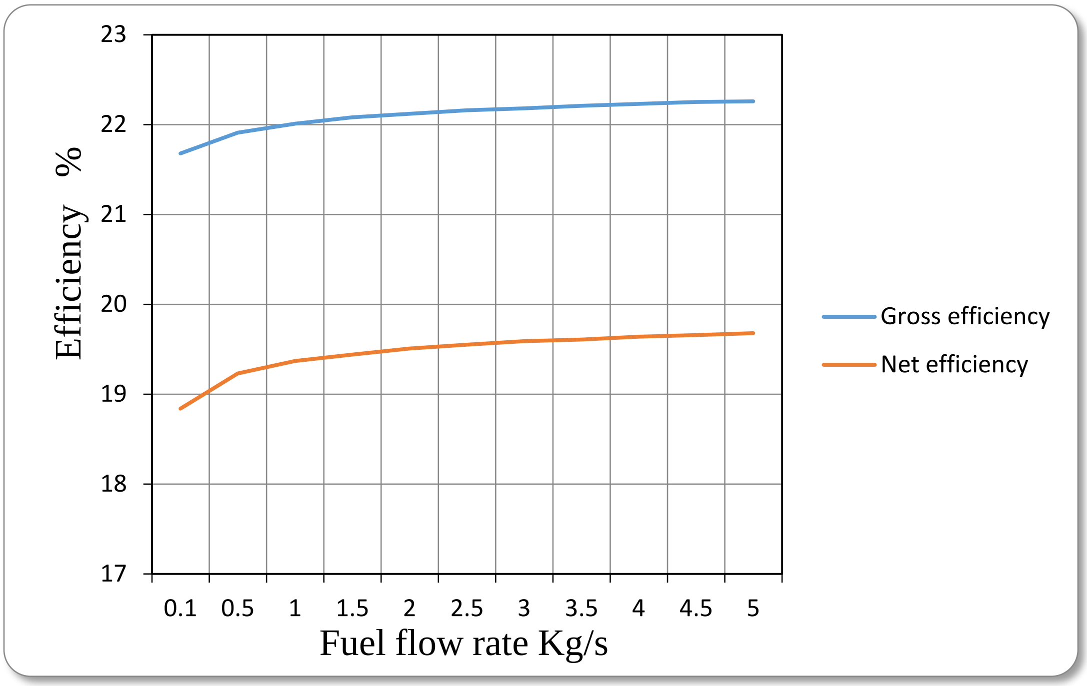


Figure 22: Fuel flow rate Versus electric efficiency

4.5. Simulation of Flue Gas Treatment

Flue gas productions from the system it depend on fuel type contain particles, alkaline metals, chlorine compound, nitrogen compound and sulfur compound. These components are no compatible with the system.

- Particles like ash, soot and dust have problem with bubbling and circulating fluidized bed gases at high concentration of solid particles in the reactor. To resolve this problem particles separate can be carried out at high temperature or low temperature. For high temperature particle separation, moving bed filters or filters containing filter candles are necessary to meet the clean gas requirements.
- Alkaline metals like potassium and sodium have a problem evaporation of salt potassium and sodium below 700^{o}C can cause deposits of ash on cooler surfaces of apparatus. To

resolve this problem by cooling the gas and eliminating fine particles where salts condensate at temperature below 600₀C.

- Chlorine compound like HCl have problem corrosion or emissions. To resolve these problem wet scrubbing eliminates certain chlorine compounds most importantly HCl nitrogen compound and sulfur compound
- Nitrogen compound like N_2 and HCN have problem polluted emissions as a result of the ammonia. Nitrogen compounds can cause high solubility in water since their elimination from water is very difficult. To resolve these problem better to use catalytic distraction of NH_3 prior to combustion or wet scrubbing
- Sulfur compound dose not exit on the fuel.

In general cleaning flue gas from the acid gases can be carried out using calcium hydroxide ($Ca(OH)_2$), calcium carbonate ($CaCO_3$) or sodium bicarbonate ($NaHCO_3$). The injection can be done directly to the furnace, duct, hybrid (furnace and duct), or using a fluidized bed reactor (Pająk et al. 2015). Conditioned-dry sorption with hydrated lime, is carried out using a cooling tower or economizer in order to lower the flue gas temperature (130-160ºC), and obtain approximately 6 percent relative humidity, and then the hydrate is injected into a duct (most often with an active carbon). Flue gas conditioning is necessary to capillary condensation, and the formation of the hydrate shell on the surface. The process depends on HCl/SO_2 ratio, as well as on fabric filters temperature which influences SO_2 removal efficiency. Dry sorption with sodium hydrogen carbonate method is not as sensitive to humidity and HCL/SO_2, but has poor reactivity with HF and is more expensive compared to hydrated lime. In the case of soda-sorbents, the products can be deposited in some underground mines or, if in a small quantity, they can be liquidated in the sea [Karl, 2009]. Simulation result of gas composition shows in table [10] at pressure 1.0132, temperature 104.3 C , mass 2.24kg, volume $2.416m^3$, Co_2 mass flow = 0.3539kg/s.

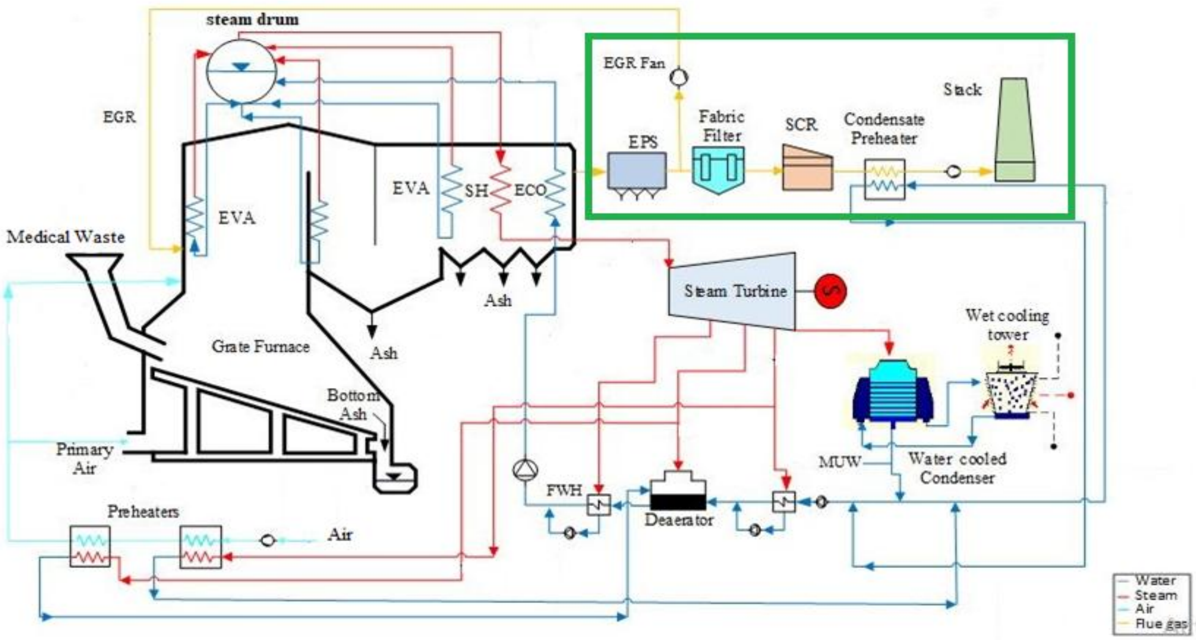


Figure 23: Flue gas treatment

Gas composition	Mole%
O_2	7.063
Co_2	10.309
H_2o	11.524
N_2	70.260
Ar	0.845
So_2	0

Table 13: flue gas composition at stack output process

As can be seen from the above two tables the flue gas composition at stack comply with emission limits [Andrzei] as all of gases except sulfur dioxide, are environmentally friendly gases that can exist naturally in air when we compare emission limit that listed in literature review table 1, 2 and 3 .

4.6. Sensitivity Analysis

Sensitivity analysis was done to see various effects on electric power generation and how the pattern of variation based on different parameters. Sensitivity analysis is used to understand different behavior of condition like when SMW collect in dry season, summer, and etc, for example in summer season SMW are very wet and have high moisture content. Those parameters are;

- Fuel flow rate,
- Ash content,
- Moisture content,
- Condenser pressure,
- Lower heating value, and
- Excess air,

These analyses show the effect on specific operational parameter: electric power generation and electric efficiency. All other operational parameters were kept constant and only the above parameters were varied.

4.6.1. Fuel flow rate

The main purpose of thermo flex software is to get power from unwanted material with environmental friendly. To see the effect of fuel flow rate on the capability power generation of the plant was simulated by increasing fuel flow rate starts from minimum then the simulation result shows that the capability of power generations were increased as fuel flow increase. The figure shows that the fuel flow and power generation are directly proportional.

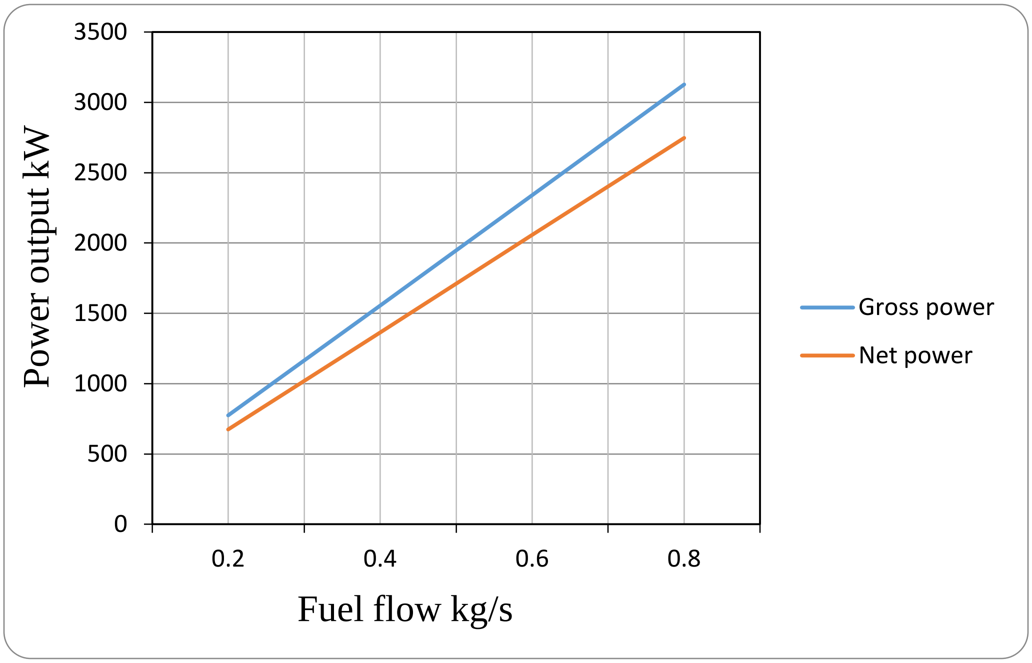


Figure 24: Effect of fuel flow rate on power output

4.6.2. Fuel ash content

The combustion process produces two main types of ash, which can be grouped as bottom ashes and fly ashes and the quantities will depend on the ash content of the waste feed material. High ash content waste usually has a low calorific value. As the ash content in waste feed increase, enough amount of heat cannot be available for the boiler for steam production which reduce steam flow rate or steam parameters which intern reduce the amount of electric power generated.

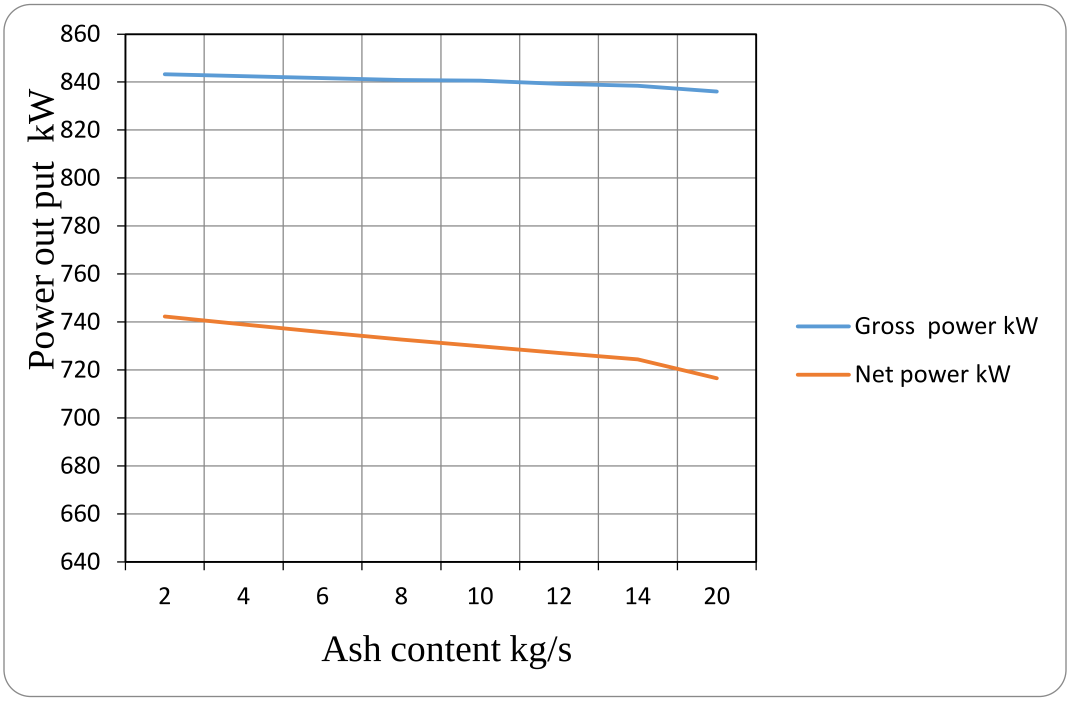


Figure 25: Effect of fuel ash content on power output

4.6.3. Moisture Content

During combustion process moisture content of SMW have big role. Wastes with low moisture content will evaporate more quickly, resulting in a higher temperature in the combustion bed. But higher moisture content takes a longer drying period and cause lower bed temperature. This necessitates utilization of auxiliary fuel to raise the temperature so as to reach adiabatic flame temperature thereby maintaining normal bed combustion. Higher moisture content of a waste lengthen the evaporation process time of the fuel, weakening the combustion process and taking up most of combustion time. That's why wastes should take a drying process before analyzing. Moisture content also has an effect on flue gas on the concentration of CO and CO_2. When moisture content is low, a great amount of CO was produced in a short time; therefore, the combustion process is short and intense. Insufficient air supply with a low O2 concentration surrounding fuel particles is also a reason for high CO concentration in the region towards the end of whole combustion process. NO concentration decreases as the moisture level in the fuel increased. Drier fuels had a higher NO due to high burning rates.

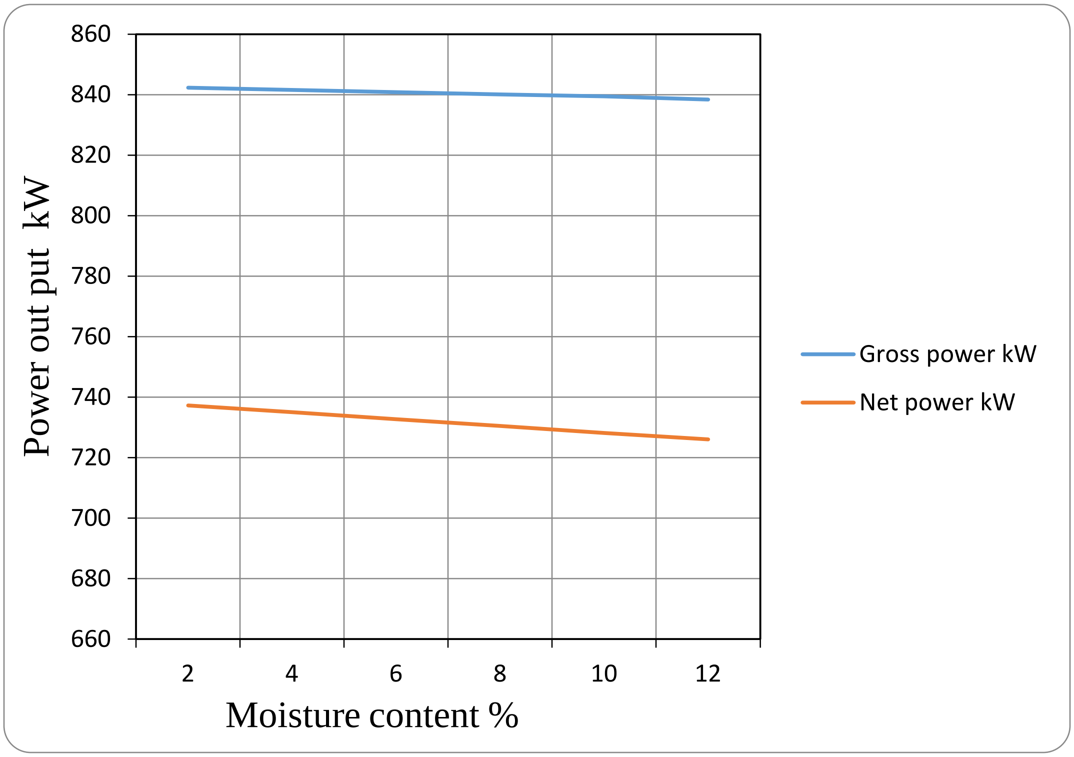


Figure 26: Effect of moisture content on power output

4.6.4. Steam condenser pressure

A steam condenser is an important component of a power plant, in which the heat of condensation is discharged to the environment. Changes of inlet temperature and mass flow rate of cooling water affect the steam pressure, which has an impact on the efficiency and power generated in the low-pressure (LP) part of the steam turbine. As steam condenser increase which intern reduces the amount of electric power generated.

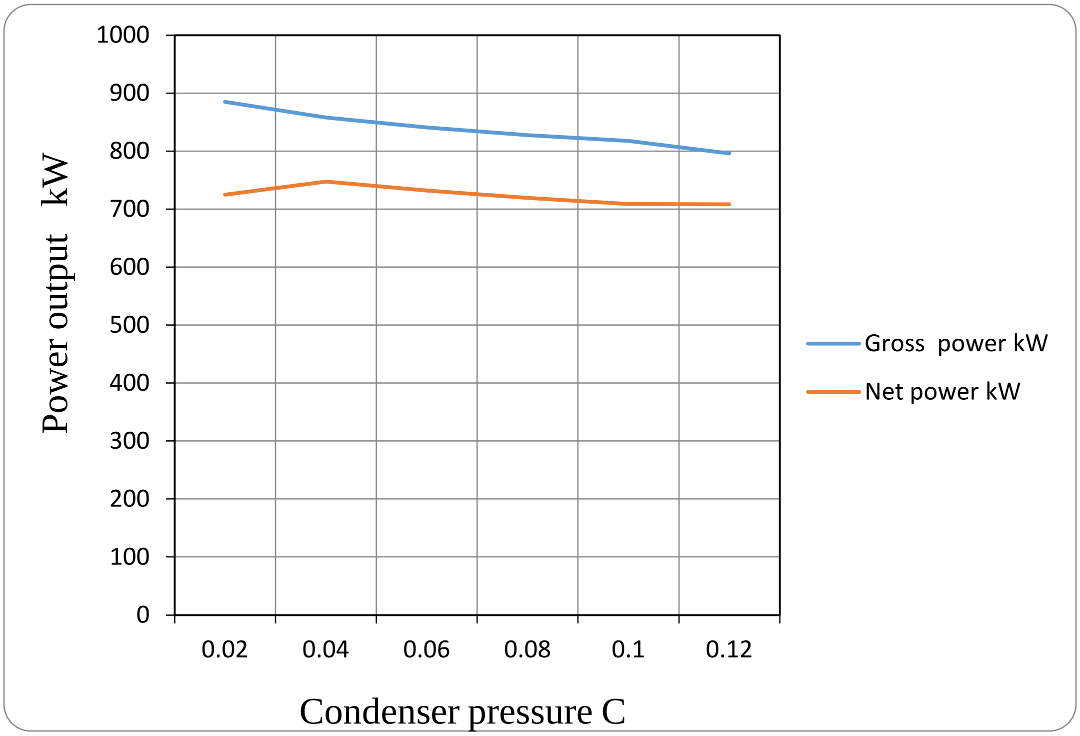


Figure 27: Effect of condenser pressure on power generation

4.6.5. Lower Heating Value

Lower heating value has high impact on the capacity of power generation, in general and specifically lower heating value obviously impact the performance of combustion process, the boiler, and overall plant efficiency which also impacts the feed rate of waste to the grate. By varying lower heating value during combustion of waste the performance of power generation was examined.

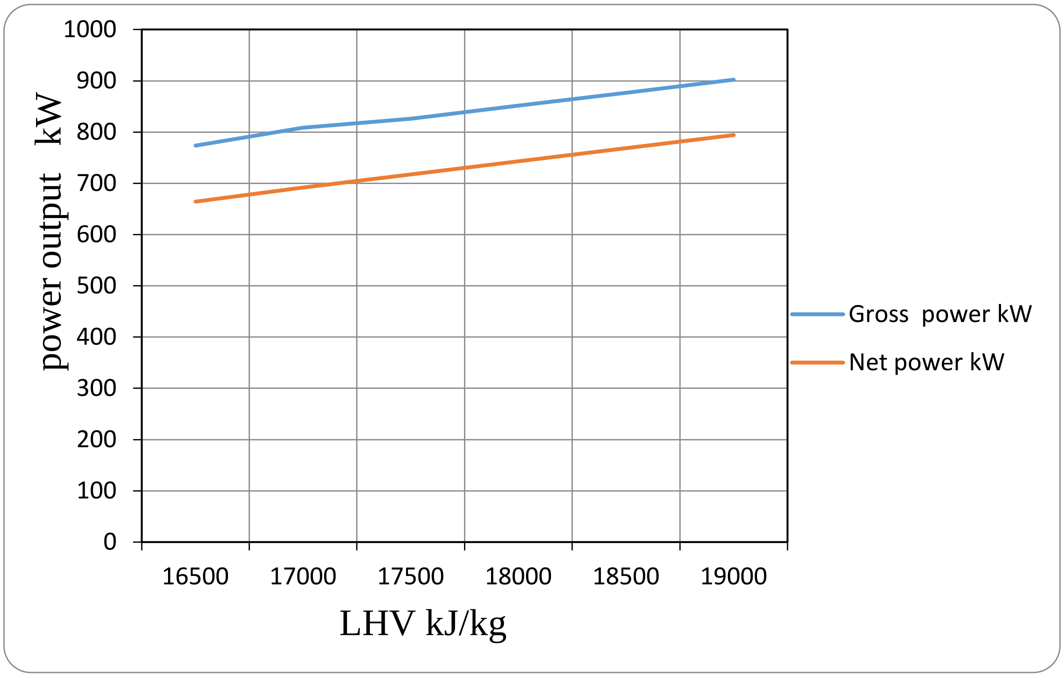


Figure 28: Effect of fuel lower heating value on power output

4.6.6. Excess air

There is a theoretical amount of fresh air that when mixed with a fixed amount of fuel and burnt will result in perfect combustion. In this situation all of the fuel will have been properly burnt and all of the oxygen in the air will have been consumed. In this circumstance there will be no excess air and combustion efficiency will be maximized. But perfect combustion is not possible. The theoretical amount of fresh air would provide insufficient oxygen for complete combustion and some of the carbon in the fuel would be converted into carbon monoxide rather than carbon dioxide. A lack of air can lead to dangerous levels of carbon monoxide being formed and smoke being produced. Therefore it is usual to adjust the combustion process so that a level of excess air is present to give margin safety. Simulation result shows that when excess air increased the capacity of power generation decreased.

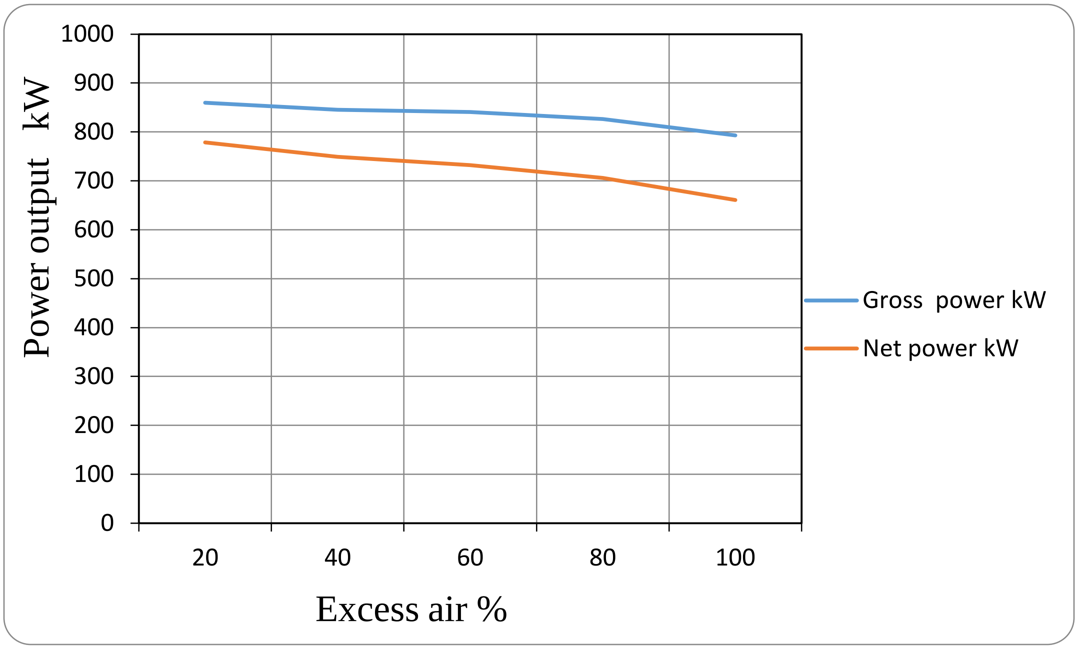


Figure 29: Effect of excess air on power output

4.7. Optimizations

4.7.1. Boiler Exit Temperature

One of the primary parameters for monitoring the performance of a power boiler is the furnace exit-gas temperature. These measurements provides a direct indication of the heat transfer to the furnace water walls at a particular load condition, and sets expectations for performance of the superheat and re-heat processes. Super heater is one of pressure parts in steam boiler. Outlet temperature in steam boiler is temperature of steam when leaves super heater that will be distributed to steam turbine. Outlet temperature in superheated is usually higher than outlet temperature in another pressure parts.

When decreasing boiler exit temperature increases both net electric power and net electric efficiency of WTE technology. It has to be noted that decreasing boiler exit temperature below limited value also has a negative impact due to the fact that it will bring low temperature corrosion problem of final heat recovery heat exchanger [59]. Boiler exit temperature and power generation are inversely proportional.

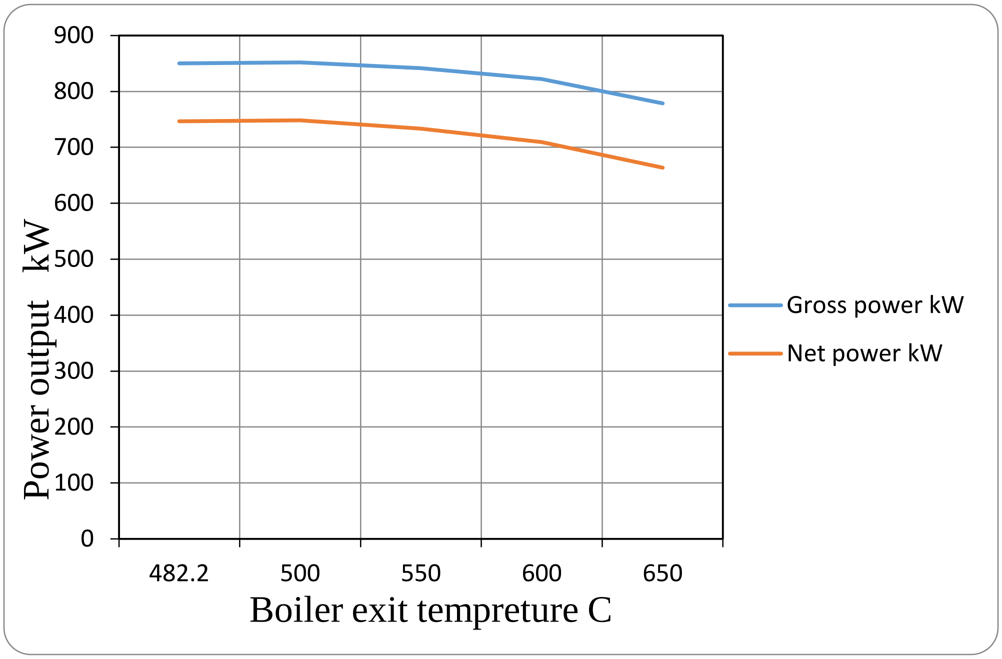


Figure 30: Effect of boiler exit temp on power output

4.7.2. Condenser Pressure

The Condenser pressure is directly linked to the amount of work done by the turbine which affects the output and hence the efficiency of the Overall cycle. By lowering the condenser pressure, the steam is condensed at a lower pressure thus resulting in more expansion through the turbine which increases the net work done by the turbine. It has to be noted that using water cooled condenser increases the efficiency of any power plants. However, we need to have a nearby river. If that is not the case, we have to use air cooled condenser. However, the efficiency of power plant using air cooled condenser is lower [59].

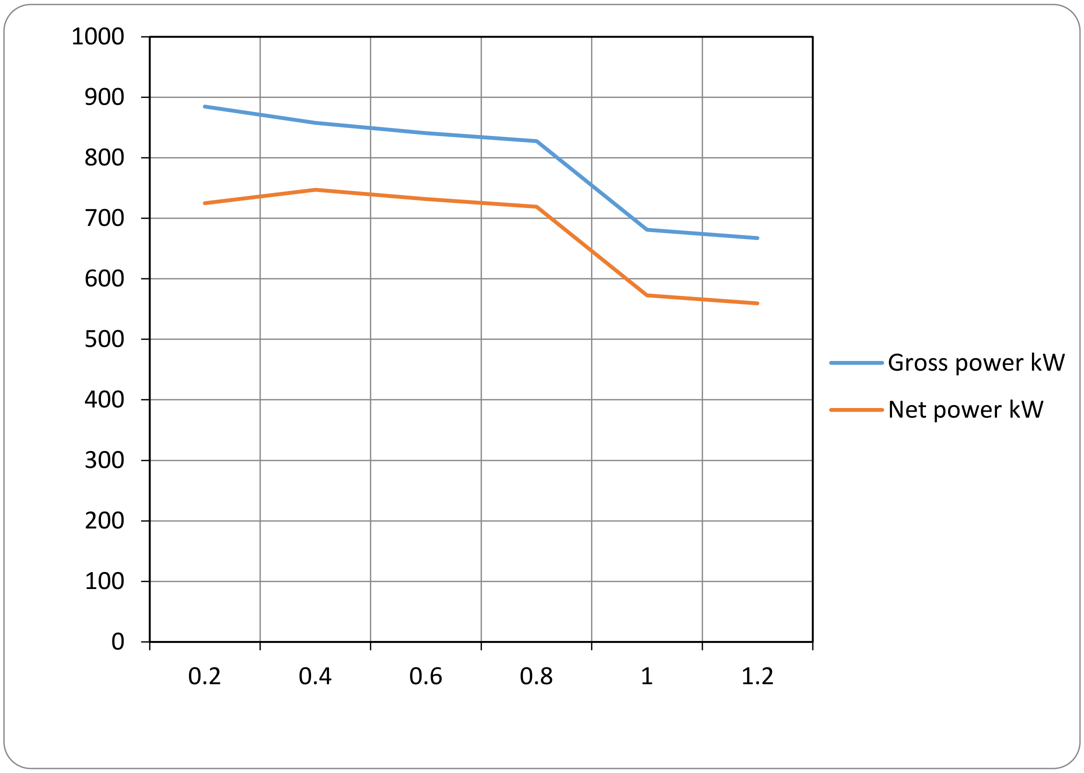


Figure 31: Effect of condenser pressure on power output

From the above optimization process the power output is increased by reducing boiler exit temperature and condenser pressure in this case there a limitation on decreasing boiler exit temperature below limited value also has a negative impact due to the fact that it will bring low temperature corrosion problem of final heat recovery heat exchanger. And also minimizing of ash content and moisture content are improving the output. **Improved power output is increased from 840.6 kW to 891.3kW or 0.84MW to 0.89MW**.

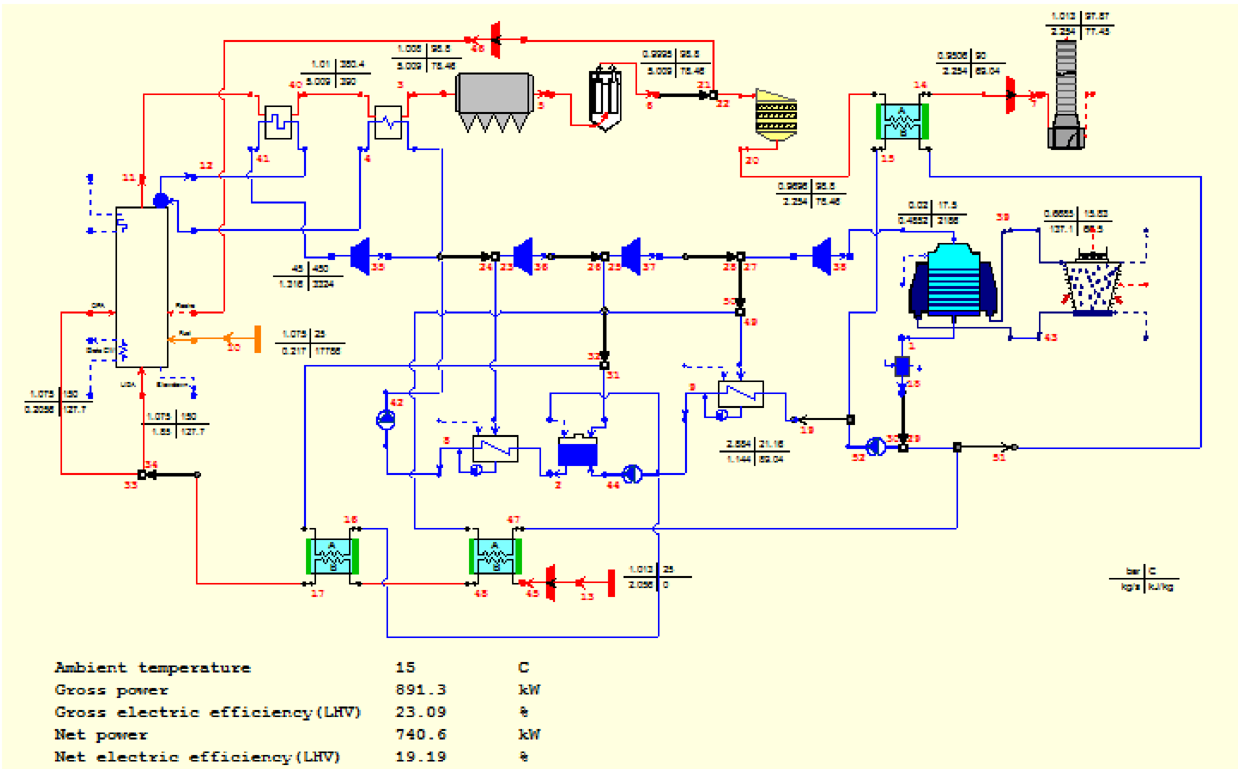


Figure 32: optimization result on power output

4.8. Cost-benefit Analysis of the WTE Technology

The handling of multiple socioeconomic and environmental concerns linked to the waste-to-energy processes and technologies vis-à-vis climate change and emission control offers inherent cost and benefits.

	Costs	Benefits
Economic	Cost reduction Reduce man power salary Reduction of fuel consumption	- Waste plastics is abundant and free - Motivates manual sorting of mixed waste and to get plastic - reduce man power - Application of results creates long term socioeconomic and environmental benefits for global sustainable development

Social	Difficulties involved in adapting to new technology Market failures due to inefficiencies of balancing negative and positive externalities	Recovery of energy from plastics solves energy, health, sanitation, pollution & city littering problems Reduce landfill space, water & ocean ecosystem pollution Obtaining alternative energy from plastics saves forest and biodiversity while mitigating climate change Offers pragmatic research with universal application in solving multiple contemporary problems
Environmental	Extra CO2 and other emissions from plastics with fossil origin influences climate change	High safety standards based on the precautionary and preventive action and correction principles is applied Experiments performed under extreme conditions with limited funds out door in winter & summer conditions Improved insulation leads to high energy production and utilization efficiency Enhances material and energy recovery from waste improving health, environmental and socioeconomic impacts Recovery of non-degradable plastics saves landfill space

Table 14: Cost benefit analysis of current method and WTE technology

Chapter Five

Conclusions and Recommendation

5.1. Conclusion

This study shows that the daily distribution of solid medical waste generation rate was highest in week days and less in weekend days. This variation happens due to flow of patients; especially OPD has high contribution because in weekend days the hospital does not give service for OPD patient except emergency cases. The result shows that the average solid medical waste generation rate was determined 1396.41kg/day from this about 68.26% was food waste, 14.68% was plastic waste, 12.84% was paper waste, 2.99% was wood waste and 1.23% was clothe waste and The estimated annual waste generation was 507,923.57 kg or 507.9 tons. In general solid medical waste management in the hospital was poor.

Using waste-to-energy simulation software, we have estimated the total output power and the annual energy generation from the steam. It is clear from the results that the output power and the annual energy generation increase by both the waste quantity and the energy content of the waste composition. When increasing the amount of fuel flow rate then the simulation result shows that the capability of power generations were increased. Its show that the fuel flow and power generation are directly proportional and we can get more power. The gross and net electric power output for a mass flow rate of 0.217 kg/hr is 0.84 MW and 0.731 MW respectively. Based on the result, the net electric efficiency of the system is 18.96 %. Based on the result is the system is affected by ash content, moisture content, excess air and lower heating value.

In general optimization process helps to increase the power output by reducing boiler exit temperature and condenser pressure in this case there was a limitation on decreasing boiler exit temperature below limited value it has a negative impact due to the fact that it will bring low temperature corrosion problem of final heat recovery heat exchanger. And also minimizing of ash content and moisture content are improving the output. The result shows the improved power output is increased from 840.6 kW to 891.3kW or 0.84MW to 0.89MW.

5.2. Recommendation

Based on the research findings the following recommendations have been made:

- Solid medical waste management must give adequate attention because of its effect on the public health and environment.
- Further studies should consider seasonal variation in SMW generation to evaluate power generation
- Detail medical waste sampling in public and private health centers at different sub city, will help to determines accurate medical waste generation rate and power generation.
- To optimize the power output reducing boiler exit temperature and condenser pressure, and also reduce ash and moisture content.
- Governmental institutions/agencies and all stockholder who have responsibility on waste management, environment protection, and energy generation have to be work together to foster the energy production from waste.

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Appendixes

Appendix 1

Solid waste generation rate in black lion specialized teaching hospital

	Food	Plastic	Wood	Clothe	Paper	Total
	Kg/day					
Day 1	1193	239	3	21	165	1621

Day 2	1205	183	16	23	198	1625
Day 3	1001	139	65	27	159	1391
Day 4	239	108	5	3	188	355
Day 5	961	152	93	8	179	1393
Day 6	975	325	23	13	174	1510
Day 7	1075	284	86	25	188	1658
Total	6649	1430	291	120	1251	9741
Average	949.86	204.29	41.57	17.14	178.71	1391.57
Percentage	68.26	14.68	2.99	1.23	12.84	100

Appendix 2

Chemistry department

Date: Thursday, June 03, 2017

Number of Samples: 2

Analysis: Elemental analysis: CHNS

Device: EA 1112 Flash CHNS/O- analyzer

Conditions: Carrier gas flow rate of 120 ml/min, reference flow rate 100 ml/min, oxygen flow rate 250 ml/min; furnace temperature of 900 C and oven temperature of 75 °C.

Calibration: 4 calibration points for every component. Samples were run in duplicate and the average values are to be taken.

Sample Code	N(%)	C(%)	H(%)	S(%)
MWT1a	0.480981	40.78345	5.856054	0
MWT1b	0.541268	45.75863	6.564746	0
MWT2a	0.468612	44.46656	6.20463	0
MWT2b	0.541614	46.88259	6.17576	0

MWT3a	1.057207	44.20624	6.669926	0
MWT3b	0.920273	44.24462	6.640183	0

Note: All three samples are not homogenous.

Appendix 3

<u>Geological survey of Ethiopia</u>

Geochemical Laboratory Directorate

Hydrocarbon laboratory analysis report format: from GD0006

File ID 1270/17pvt

Originator: Azeb Tayework

Sample type: Medical / non infectious waste

Number of sample: 3

Preparation required: 60 mesh

Element to be determined:[Moisture, volatile matter, fixed carbon and ash] and calorific value

Method of analysis: proximate Analysis and Adiabatic calorific meter.

Field no.	Lab no.	Moisture %	Volatile matter %	Fixed carbon %	Ash %	Calorific value %
MWT-01	1270/17	6.75	73.68	11.88	7.69	4224.18
MWT-02	1271/17	6.68	73.19	11.85	7.85	4259.22
MWT-03	1272/17	7.03	71.50	11.74	9.73	4463.63
MWT-03	1272/17dup	6.52	72.73	11.76	8.99	4437.46

Appendix 4

Fuel flow rate versus power output

Fuel flow rate Kg/s	Power output kW	
	Gross power	Net power
0.157	446.3	387.8
0.217	840.6	731.9
0.3	1164.7	1018
0.5	1948.2	1710.4
1	3915	3444
2	7869	6942
3	10451	11837
4	13971	15815

Appendix 5

Fuel flow rate versus electric efficiency

Fuel flow Kg/s	Gross efficiency	Net efficiency
0.1	21.68	18.84
0.5	21.91	19.23
1	22.01	19.37
1.5	22.08	19.44
2	22.12	19.51
2.5	22.16	19.55
3	22.18	19.59
3.5	22.21	19.61
4	22.23	19.64
4.5	22.25	19.66
5	22.26	19.68

Appendix 6

Effect of ash content on power output

Ash content kg/s	Gross power kW	Net power kW
2	843.2	742.3
4	842.4	738.9
6	841.6	735.7
8	840.8	732.7
10	840.6	729.9
12	839.2	727.1
14	838.4	724.4
20	836	716.5

Appendix 7

Effect of Moisture content on power output

Moisture content %	Gross power kW	Net power kW
2	842.3	737.3
4	841.5	735
6	840.8	732.7
8	840.1	730.5
10	839.4	728.2
12	838.4	726

Appendix 8

Effect of condenser pressure on power output

Condenser pressure C	Gross power kW	Net power kW
0.02	884.8	724.7
0.04	857.7	747.2
0.06	840.5	731.9
0.08	827.7	719.1
0.1	817.4	708.8

0.12	796.18	708.37

Appendix 9

Effect of low hating value on power output

LHV kJ/kg	Gross power kW	Net power kW
16500	773.8	664.3
17000	808.8	691.6
17500	826.1	717.2
18000	851.4	742.9
18500	876.7	768.5
19000	902	794.1

Appendix 10

Effect of excess air on power output

Excess air %	Gross power kW	Net power kW
20	859.7	778.8
40	845.3	748.9
60	840.5	731.9
80	826.5	705.9
100	792.9	660.5

Appendix 11

Boiler Exit Temperature

Boiler exit temperature C	Gross power kW	Net power kW
482.2	850	746.7
500	851.6	748.1

550	841.3	733.1
600	822.1	709.6
650	778.7	663.4

Appendix 12

Condenser pressure

Condenser pressure C	Gross power kW	Net power kW
0.2	884.8	724.7
0.4	857.7	747.2
0.6	840.5	731.9
0.8	827.7	719.1
1	680.8	572.8
1.2	667.2	559.3

Addis Ababa University

Addis Ababa Institute of Technology

Biomedical Engineering Department

Evaluation of Energy Potential from solid medical waste at Tikur Anbessa Specialized Hospital

DECLARATION

The undersigned declare that this thesis is my original work and has not been presented for a degree in any other university, and that all sources of material used for the thesis been dully acknowledgment.

Azeb Tayework

Confirmed by:

Name: Wondwossen Bogale (Dr. Ing)	Name: Masreshaw Demelash (Dr.)
Signature: ____________________________	Signature: _______________________________
Date: ____________________________	Date: ________________________________