Feasibility Study of Solar Assisted Waste-to-Energy Power Plant for Adama City

M.Sc. Thesis

By

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Adama, Ethiopia

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Advisor: Dr. Dawit Gudeta

A Thesis Submitted to Thermal and Aerospace Engineering Department of school of Mechanical, Chemical and Materials Engineering, Adama Science and Technology University in partial fulfillment of the requirement for the Award of the Degree of Master of Science in Thermal Engineering.

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APPROVAL BY BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiners of the final open defense by Redwan Ali have read and evaluated his thesis entitled "Feasibility study of Solar assisted Waste-to-Energy power plant for Adama city" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Master of Science in Thermal Engineering.

Chairperson	Signature	Date
Internal Examiner	Signature	Date
External Examiner	Signature	Date

Declaration

I hereby declare that this M.Sc. Thesis entitled "Feasibility study of Solar assisted Waste-to-Energy Power plant for Adama city" in partial fulfillment of the requirement of the own work carried out from September 2018 to September 2019 under supervision of Dr. Dawit Gudeta, Thermal Engineering Department, Adama Science and Technology University.

The matter embedded in this thesis has not been submitted for the award of a degree or diploma in any other university, All relevant resource information used in this paper has been duly acknowledged.

Redwan Ali	……………………	………………......
Student	Signature	Date

This is to certify that the above statement made by the candidate is correct to the best of our knowledge and belief. This has been submitted for examination with our approval.

Dr. Dawit Gudeta	……………………..	………………….
Advisor	Signature	Date

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ABSTRACT

The thesis outlined in this report is a pre-feasibility study of the potential to use waste-to-energy technology in Adama city. The project aimed to show (explore) Adama city's economic and environmental opportunities for solid waste incineration with energy recovery, also known as Waste to Energy.

The current waste management system in Adama consists of landfills in the cities and open burning. Environmentally, this is a poor solution and although there are plans for change, no specific strategy has been presented. This is a growing problem both environmentally and logistically. Another important thing is that Waste to Energy is the additional way of getting energy for Adama city.

Data was collected from Adama with four kebele and different literature review. From the collected data, waste-to-energy systems were simulated in CYCLEPAD, Python, and MECH IN EXCEL. Results from the simulations show that a system using waste incineration would be the best solution for the Adama city.

The results of this study show that implementation of a waste incineration plant in the Adama city energy system is economically and environmentally feasible, when compare to the current conditions. The chosen system is designed to handle a total of 50,000 tons of waste annually collected from Adama city. The system will provide 118.5 GWh electric energy annually. The system investment cost is around 149.5 MUSD and it is expected to generate an annual profit 4.71 MUSD. The results in this study clearly show that there are both economic and environmental potential for waste-to-energy technologies in the region.

By implementing waste-to-energy technology, the supplied waste can be seen as a resource instead of a problem. This would give incentives for further actions and investments regarding waste management. Compared with city's current solution with landfills and fossil fuel turbines, the project also develop a significant environmental improvement. During the plant's design lifetime, greenhouse gas emissions are small with the assumption that only a portion of the carbon content of the waste is of fossil origin.

Key words: Municipal solid waste (MSW), Power generation or production

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LIST OF ABBREVIATIONS

ACM0002	Approved consolidated baseline methodology 0002
a.g.l	Above ground level
a.s.l	Above sea level
B/C	Benefit /Cost (ratio)
CAPM	Capital Asset Pricing Model
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CIRR	Commercial interest Reference Rate
DNA	Designated national Authority
DPP	Diesel Power Plant
EEPCo	Ethiopian Electric power Corporation
EF	Emission Factor
EIRR	Economic internal Rate of Return
ENPV	Economic Net present value
EPA	Ethiopian Environmental protection Authority
EPRA	Emission Reduction Purchase Agreement
ETB	Ethiopian Birr
FIRR	Financial Internal Rate of Return
FOCC	Financial Opportunity Cost of Capital
FX	Foreign Exchange
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse Gas
HFO	Heavy fuel oil

HOB	Heat only Boiler
ha	hectare
IRR	Internal rate of return
Ipcc	Intergovernmental panel on climate change
KP	Kyoto Protocol
KWh	Kilowatt-hour
MSW	Municipal Solid Waste
NCV	Net Calorific Value
NPV	Net Present Value
NOx	Mono nitrous oxides
O&M	Operation and Maintenance
PDD	Project Design Document
SNCR	Selective Non-Catalytic Reduction
SCR	Selective Catalytic Reduction
T[HP]	High pressure turbine
T[LP]	Low pressure turbine
TOC	Toxic Organic Compound
TPP	Thermal Power Plant
UNEFCC	United Nations Framework on Climate Change
WTE	Waste-to-Energy

CHAPTER ONE
INTRODUCTION

1. Background of the study

Waste is an unwanted material that is of no use to the owner and hence is disposed off in open area. Disposal onto the land or water body is not the solution as they create huge problem to the environment and health of the human beings. Moreover, the polluter pay principle of environmental protection act has forced the industries to treat the waste prior to disposal (Garg, 2016).

Thermal treatment uses high temperature to degrade or destruct the waste. There are 600 waste-to-energy facilities and more are being constructed in many parts of the world today. As countries implement more stringent environment regulations for landfills, waste-to-energy technology is quickly becoming the choice for the cost effective, energy efficient and environmentally friendly. They are designed to thermally degrade the waste and recover energy in the form of heat or electricity. Its main purpose is to reduce the impact of residual waste on the environment (Yogalakshmi, 2014).

Incineration is a type of combustion where waste is oxidized at high temperature of 900-1200^{0}C to produce carbon dioxide, water and a residue `ash`. Though incineration reduces 90% of waste by volume, it generates huge amount of gaseous and particulate pollutants (Sunil, 2014).

Municipal solid waste (MSW) is composed of different wastes generated by households, commercial and industrial premises, institutions such as schools. Hospitals, care homes and prisons, and from public spaces such as streets, markets, slaughter house, public toilets, bus stops, parks, and gardens. Developing countries have undergone a rapid urbanization during the past many years and the number of residents is expected to double between 1987 and 2015 (Yogalakshmi, 2014).

Adama city administration revealed that the annual SW collection by the street sweepers is 2340 m^3 comprising of 43% collected out of the 3750m^3 SW generated from the streets. The low performance is due to the inadequate number of dust bins in the locality and the lack of public awareness to drop SW, especially paper and plastic materials in the dust bins (Mengist, 2014).

The nature of municipal solid waste mainly includes physical, chemical and sensory properties. The nature of municipal solid waste is closely related to its composition. Physical properties of MSW mostly refer to moisture content, bulk density, calorific value; chemical properties refer to an elemental composition, ash, and volatile grading (Mengist, 2014).

Knowledge of the calorific value of post-recycling MSW is necessary since its part that is not landfilled can be the fuel of a WTE furnace (Themelis et al, 2012). Found that the closely approximated chemical formula of the mix of organic compounds in MSW can be expressed as

$C_6H_{10}O_4$. The chemical equation for full combustion of the organic compounds in MSW is shown as following $C_6H_{10}O_4+6.5O_2 = 6CO_2+5H_2O$ (Zucheng Guo, 2015).

The total amount of MSW disposed of worldwide to landfill is 380 million tons, recycle 180 million tons, waste to energy (WTE) 140million tons, dump 75million tons, compost 70 million tons, and others 50 million tons. Landfill and recycle are the most common techniques of treatment (Hoornweg and Bhada-Tata, 2012). Total MSW disposed of worldwide in millions of tons/year and disposal options are presented in Figure 1.1

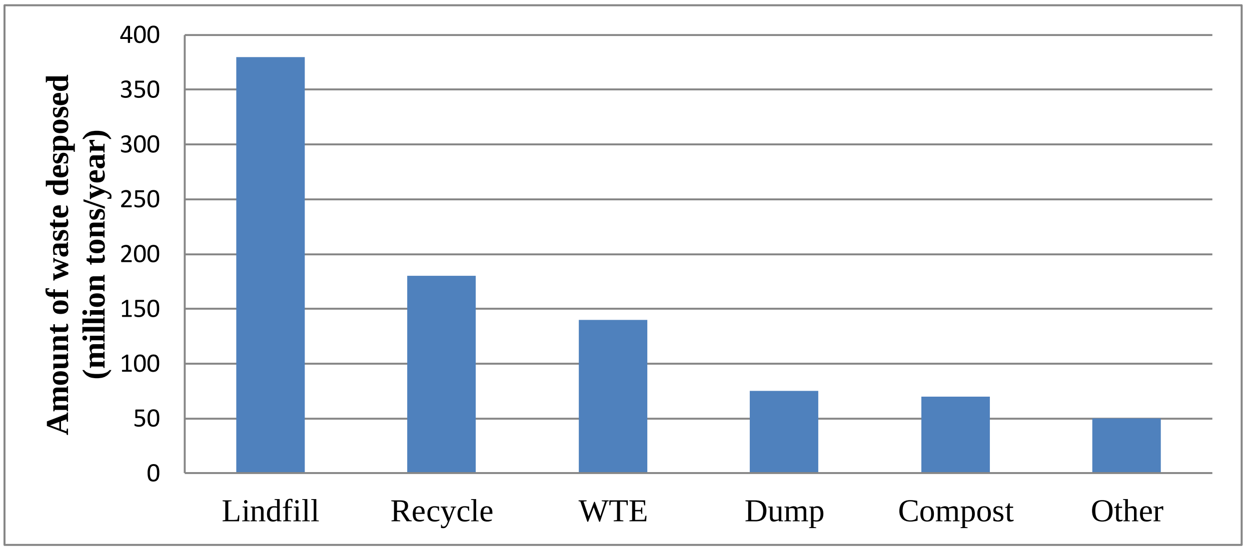

Figure 1.1 Total MSW disposed of Worldwide in millions of tones/year (Hoomweg and Bhada, 2012)

1.1.2. Waste management

Energy production, waste to energy, is one alternative and aspect of waste management. Energy production is one component of waste management hierarchy. Proper waste management is a source of energy production. To manage the constantly increasing generated municipal waste, development and application of waste to energy technologies becomes crucial. This is the reason why many countries build and operate waste to energy technologies to manage the continuously rising produced municipal solid waste. Waste management using energy technology turns waste to energy production (Aron, 2017).

1.1.3. Current waste management practices

In Ethiopian city especially in Addis Ababa alone, the open burning of MSW and landfill fires emits nearly 2,000 tons per year of pollutants into the air. These pollutants include carbon Monoxide (CO), Hydrocarbons (HC), Particulate Matter (PM), Nitrogen Oxides (NOx) and Sulfur Dioxide (SO_2) plus an estimated 750 TEQ grams of dioxins/furans. Researchers examine that, since open burning occurs at ground level, that resultant emissions enter the lower-level breathing zone of the atmosphere, increasing direct exposure to humans.

Researcher observed that the role of the informal sector in SWM in developing nations is increasingly being recognized. Thy estimated that every ton per day of recyclables collected informally saves industry ETB 8,7500 per year in expenditures (i.e., recycled metal replaces the need to purchase new metal) and avoids the emission of 721 kg of carbon dioxide per year.

Municipal solid waste generated in Ethiopia in the next decade were to be composted as mixed waste and used for agriculture, it would introduce 7,000 tons of heavy metals into agricultural soils. The investigation also found that the calorific value of some composting reject materials is as high as 11.6 MJ/kg (2770 kcal/kg). This value is much higher than the minimum calorific values of 5.5 MJ/kg recommended for economically feasible energy generation through Cambridge industries plants (Cambridge, 2017).

In 2011, due to inadequate separation procedures, Ethiopia landfilled an estimated 300,000 tons of recyclable material, which could have been used as secondary raw materials in manufacturing industries. A further 600,000 tons of compost, which could have been used as fertilizer supplements, are estimated to have been landfilled duet to the absence of source separation facilities. 5.8 million barrels of oil energy equivalent in waste-to-energy feedstock are estimated to have been landfilled due to the absence of waste-to-energy facilities.

Coming two decades of economic growth will change the composition of Ethiopian waste, and the quantity of municipal solid waste generated will increase rapidly due to a growing population and improvement in lifestyle. Land in the city is scarce and public health and environmental resources are precious. The feasibility study acknowledges that materials and energy recovery from waste is an important aspect of improving municipal solid waste in Ethiopia. It not only adds value to MSW projects and makes them economically feasible but also more environmentally sustainable the following Table1. 1 shows the MSW heat content and Biogenic shares (Cambridge, 2017).

Table1. 1 Municipal Solid waste (MSW) heat content and Biogenic shares study

Sample No.	Heat content (million Btu/Ton)	Share of Total MSW Energy	Column1
		Biogenic	Non-Biogenic
1	9.32	0.54	0.49
2	9.43	0.51	0.49
3	9.59	0.52	0.48
4	9.67	0.58	0.42
5	9.67	0.51	0.49
6	10.08	0.56	0.44

1.1.4. Basics of a waste-to-energy power plant

Waste incineration became established in many European Countries at the end of the nineteenth century as a device to minimize waste's volume and to make it hygienic. Since then, as environmental awareness has increased, WTE technology has continuously developed and improved, increasing the importance of efficient energy generation. WTE power plants, in many European countries, have become important tools to generate heat and electricity, replacing the energy produced by conventional fossil fuel power plants (Lisa, 2015).

The dominant technology for energy recovery from municipal solid waste (MSW) is direct combustion over a moving grate with the generation of superheated steam feeding a steam turbine. The amount of energy recovered from the MSW combustion can vary significantly with the characteristics of MSW fed into the boiler (composition; mass flow rate; and lower heating value, LHV), the combustion technology, the configuration and features of the recovery boiler (adiabatic or integrated), and the characteristics of the thermodynamic cycle (Lisa, 2015). A simplified and schematic representation of a WTE power plant is shown in Figure1. 2 highlighting four macro processes and related plant sections:

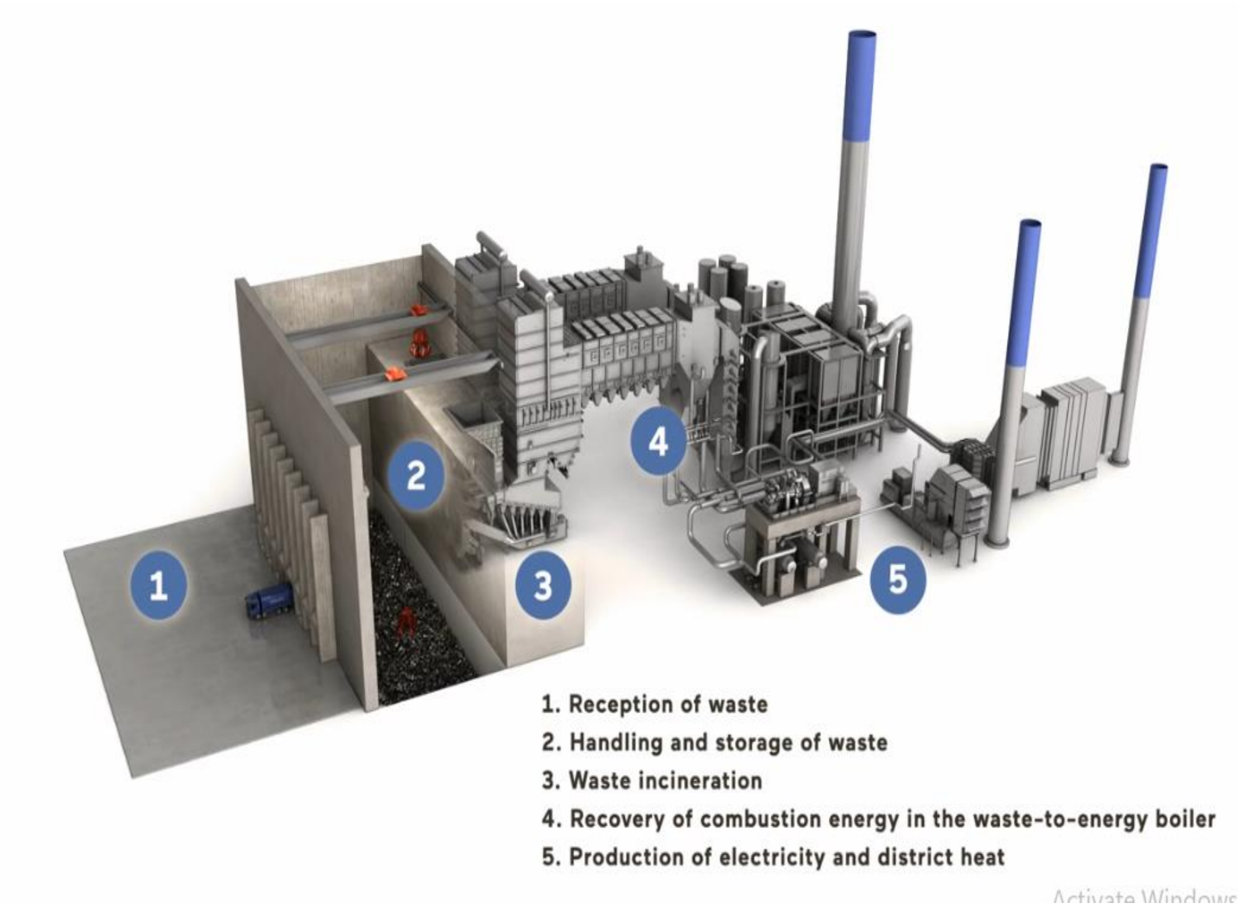

Figure 1. 2 Schematic of a WTE power plant highlighting four macro sections

1.1.4.1. Waste delivery and storage section

Trucks, trains, or containers arrive at the delivery area in order to dump the waste into the bunker, usually after visual control and weighing. Enclosure of the delivery area can be an effective means to avoid odor, nose, and emission problems. The bunker is usually a waterproof concrete bed. The waste is piled and mixed in bunker using cranes equipped with grapples. The mixing of the waste helps achieve a balanced heat value, size, structure, composition, etc., of the material dumped into the combustion section. In order to avoid excessive dust development and gas formation (e.g., methane) from spontaneous chemical reactions between the disposals, as well as the accumulation of odor and dust emissions, waste has to be permanently moved, mixed, and turned by crane operators. Moreover, depending on the calorific value of the waste as well as the layout and the concept of the plant, a fraction of total combustion air (usually the under-grate air) is extracted from the bunker. The bunker usually has a storage capacity of several days (commonly 3-5 days) of the plan operation throughput; thus its depth can reach a few dozen meters (Lisa, 2015).

Proper waste feeding from bunker to grate means dosing the right quantity of fuel for steady combustion. Therefore, waste feeding is continuously adjusted as a consequence of achieved combustion temperature and energy production. Table1. 2 shows the schematically presents the purpose of the main components of a WTE power plant (Lisa, 2015).

Table1. 2 Purpose of the main Components of a waste incineration plant

Objective	Responsibility
Delivery and storage of waste	Bunker
Mixing of waste	
Feeding of waste to combustion section	
Destruction of organic substance	Furnace
Evaporation of volatile heavy metals and inorganic salts	
Production of potentially exploitable slag	
Volume reduction of residues	
Evaporation of water	Energy conversion section
Recovery of useful energy	
Removal and concentration of Volatile heavy Metals and inorganic matter into solid residues	Flue gas cleaning
Minimizing emission to all media	

1.1.5. Waste to energy conversion pathways

There are three main pathways employed by Cambridge industries for conversion of waste or garbage material to energy; thermo-chemical, biochemical, and physicochemical.

Plant thermo-chemical conversion, characterized by higher temperatures and conversion rates, is the suited for lower-moisture feedstock or feedstock that has been dried through a Cambridge industries Dryer (CID). This process works very well for leveraging resources from landfills and serving as a replacement to landfills as a waste management solution. Thermo-chemical conversion includes green incineration, pyrolysis and gasification (Cambridge, 2017).

The green incineration technology is the controlled combustion of waste with the recovery of heat to produce steam, which in turn produces power through steam turbines. Pyrolysis and gasification represent refined thermal treatment methods, which serve as alternatives to incineration and are characterized by the transformation of the waste into gas as an energy carrier for later combustion in, for example, a boiler or a gas engine.

Bio-chemical conversion processes, which include anaerobic digestion and fermentation, are preferred for waste with a high percentage of organic biodegradable (putrescible) matter and high moisture content. Anaerobic digestion can be used to recovers both nutrients and energy contained in organic wastes, such as animal manure. The process generates gases with a high content of methane (55-70%) as well as bio-fertilizer. Alcohol fermentation is the transformation of organic fraction of waste to ethanol by a series of biochemical reactions using specialized microorganisms.

Physicochemical conversion technology involves various processes to improve physical and chemical properties of solid waste. The combustible fraction of the waste is converted into high-energy fuel pellets, which may be used in steam generation. Fuel pellets have several distinct advantages over coal and wood because they are cleaner, free from incombustibles, have lower ash and moisture contents are of uniform size, are cost-effective, and eco-friendly.

Thermal processing technologies involve combustion of solid waste to generate energy. The combustion generates heat that can be used directly or converted into electrical energy. The most common technology of this kind is conventional incineration. More advanced technologies such as pyrolysis and gasification can produce a more versatile range of products such as syngas, liquid and solid fuels, heat and electricity. These advanced technologies are in the early stages of commercial development (Cambridge, 2017).

1.1.6. Factors affecting energy recovery

The two main factors, which determine the potential of recovery of energy from waste, are the quantity and the quality (physicochemical characteristics) to the waste. Some of the important physicochemical parameters requiring consideration in choosing a waste-to-energy technology include: (Cambridge, 2017).

- Size of constituents
- Density
- Moisture content
- Volatile solids / Organic matter
- Fixed carbon
- Total inerts

- Calorific value

1.1.7. Combustion process

Combustion is process by which a material is burned in the presence of oxygen. It is an exothermic reaction between the substance being burnt and oxygen. Combustion breaks down the organic and inorganic substances into stable end products such as carbon dioxide and water. The predominant reactions occur between carbon and hydrogen with oxygen in air to from carbon dioxide and water. Oxides of sulphur (Sox) and nitrogen (NOx) are other products of combustion. Insufficient oxygen can affect the combustion process and result in formation of carbon monoxide and hydrogen chloride (when hydrogen reacts with organic chlorine molecules (Cambridge, 2017).

Carbon monoxide is harmful and hence to avoid its formation sufficient oxygen should be flushed into the chamber. All combustion furnaces should be provided with good mixing facilities to provide uniform distribution of air throughout the waste material and other gases released during the burning of waste. At the end of combustion process, an incombustible particulate matter termed `bottom ash` is left behind in the combustion chamber. The particulate matter is emitted outside the chamber along with the flue gas and they are termed as `fly ash`. Incineration is the best example of combustion (Cambridge, 2017).

There are two main types of furnaces in Waste-to-Energy power plants; those are the moving grate incinerator and the fluidized bed.

1.1.7.1. Fluidized bed

In a fluidized bed the incineration process is done in a bed of sand and waste. The waste is reduced into small particles that are used in the furnace. Combustion air is blowing through the bed from below to transform the bed into a liquid-like state, waste particles are added and mixed with the sand as it is combusted. The temperature in furnaces of this kind is usually around 900^0c. Bubbling fluidized bed and circulating fluidized bed are the two main types used for commercial use (Johan & jon, 2015). A circulating fluidized bed boiler is shown in Figure1.3.

For waste streams with a homogeneous calorific value the fluidized bed technology gives a higher efficiency compared to the moving grate technology. On the contrary the fluidized bed technology cannot process waste feedstock with a wide variety of quality or high moisture waste in an efficient manner. It also requires pre-sorting and shredding of the waste feedstock, which tend to increase the operating cost compared to the moving grate technology (Alvarez, 2006)

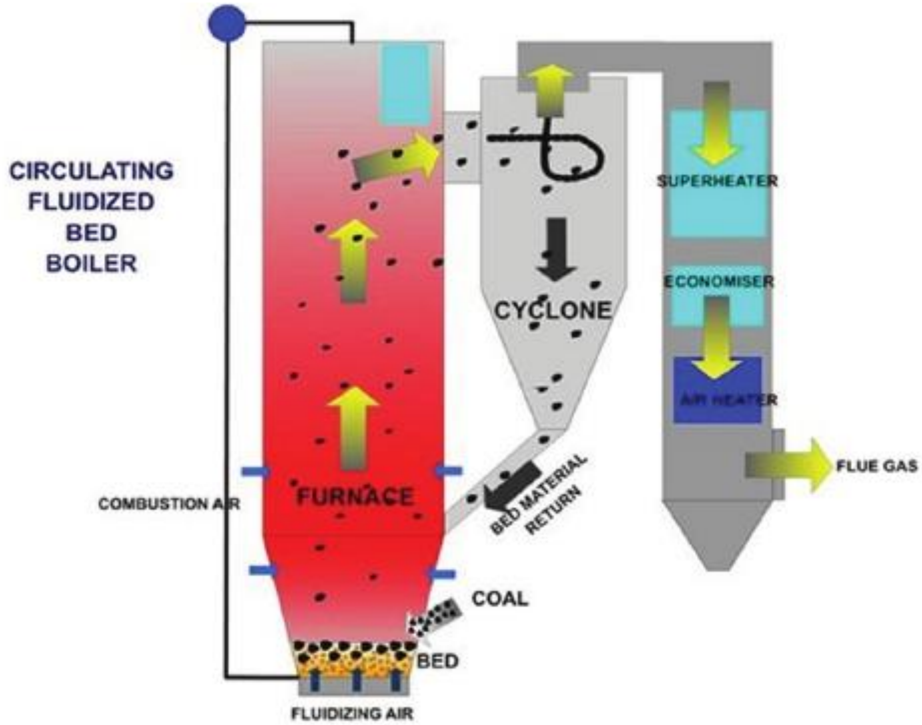

Figure 1. 3 Fluidized bed (Bright hub engineering, 2009)

1.1.7.2. Moving grate

The moving grate incinerator technology is the most used WTE technology thanks to its durability and ability to process a variation of waste composition. A crane feeds waste to the moving grate from a storage bunker, where the waste has been mixed and stored. The grate consists of separate moving parts that slowly move the waste further into the incinerator. During the transportation on the moving grate the waste is evenly distributed and dried before combustion. When the dried waste reaches the incinerator combustion takes places (Johan & jon, 2015).

The combustion process is a chemical reaction between elements in the waste fuel and oxygen from the input air. During combustion flue gas is formed and heat is released. Dross is a residue from the combustion process that consists of non-combustible or unburned parts of the fuel (Alvarez, 2006). A simple figure of the combustion process is shown in Figure 1.4. Formulas for the chemical reactions are shown in Equation 1.1 and 1.2.

$$C+O_2 \rightleftharpoons CO_2 + \text{heat} \quad (1.1)$$

$$2H_2+O_2 \rightleftharpoons 2H_2O+\text{heat} \quad (1.2)$$

To get a full and efficient combustion it is vital to have a high temperature, sufficient access of oxygen and a steady circulation of the waste. It is also important to maintain a constant supply of fuel. If the combustion is incomplete it produces undesirable emissions like carbon monoxide and hydrocarbons, it also lowers the efficiency (Alvarez, 2006)

To get a close to complete combustion, air is supplied through the gate from below. This air supply has the purpose to oxygenate the waste as well as to cool down the grate. Secondary combustion air is also supplied straight to the incinerator through nozzles above the grate. The air supplied to improve turbulence and give a surplus of oxygen to ensure a full combustion (Johan & jon, 2015).

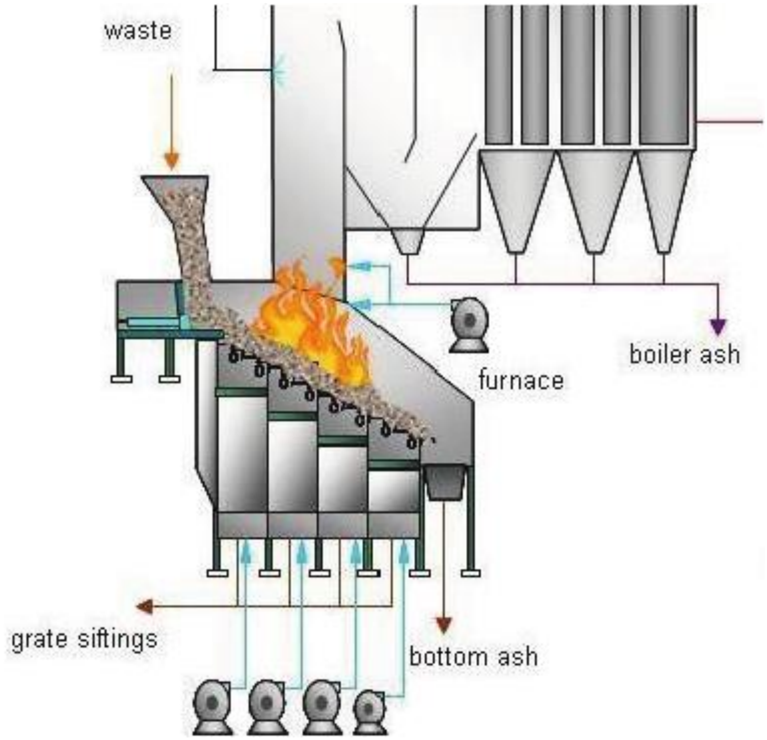

Figure 1. 4 Combustion Process in a moving grate (Lahl, 2012)

In order to ensure proper breakdown of toxic organic substances the flue gas has to be at least 850^0c for at least two seconds. According to (Alvarez, 2006) this temperature is reached when it is $1,300^0$c in the furnace. There are auxiliary burners in the furnace that make sure that the temperature is reached if the calorific value of the waste is not high enough to maintain the desired temperature (Coolsweep, 2012).

The capacity of moving grate plants can vary significantly both in terms of waste input and energy output, a typical capacity is around 30-40ton/hour (Coolsweep, 2012).Moving grate plants have a lower investment costs, but also lower efficiency compared to other incineration technologies. The main advantages with the moving grate are the capacity to handle waste that has not been pre-treated and its ability to accommodate large variations in waste composition and calorific value (Lampreia & Tumiwa, 2014**).**

1.1.8. Waste incineration

The meaning incineration has no more reliable definition in the attention of the community because of the ineffective process of certain waste combustors in olden times. Consequently, the word waste-to-energy combustion is nowadays commonly applying instead. Waste incineration is the most established technology for waste-to-energy recovery. According to Coolsweep around 2,000 conventional incineration plants are in service today, and together they have a capacity to process 100 million tons of waste per year. The energy recovery process in an incineration plant is simple. Through combustion of waste heat is generated, which is used to produce steam. The steam can, depending on the local demand either be used to generate only electricity or heat.

To increase the efficiency both heat and electricity can be generated in a combined heat and power plant, CHP. Depending on technology the net electrical efficiencies varies from 17 to 30%, while CHP plants have energy efficiencies as high as 80%. Here, incineration therefore, denotes the contemporary exercise of incineration of waste that cannot be reprocessed in an economical manner. Incineration provides high opportunities lessening the size of waste to the landfill and in making heat and power. Fresh solid waste provides a heating value from 9.3MJ/kg to 16.3 MJ/kg where the source separation of bio-waste works well compared to coal that discharges almost 23.3 MJ/kg. Therefore, a big quantity of heat can be discharged through combusting municipal waste so that heat is utilized to produce electricity (Coolsweep, 2012). Incineration is a combustion process in which the waste material is burned in the presence of oxygen by applying high temperature of 900-1200^{0}C. This temperature is selected to ensure

- good combustion
- complete elimination of odours and
- protection of the walls of the incinerator

Incineration is referred to as thermal treatment and is considered as the best alternative route for disposal of solid waste. During the process of incineration, the waste material is oxidized to produce ash, flue gas and heat along with water vapour, nitrogen, carbon dioxide and oxygen (Cambridge, 2017**)**.

In addition to carbon dioxide, other gases such as carbon monoxide, hydrogen chloride, hydrogen fluoride, nitrogen oxides, sulphur dioxide, volatile organic carbon, dioxins, furans, polychlorinated biphenyls are also produced depending on the nature of waste and the availability of oxygen **(**Alvarez, 2006).

Incineration involves the combustion of organic materials into incinerator bottom ash, flue gases, particulates, and heat, which can be used to generate electricity. The heat produced upon incineration of dried waste can be used to generate steam, which can be used to drive a turbine in order to produce electricity. Incineration is banned in most OECD countries due to its environmental impact, such as toxic emissions and the poor energy recovery from the wasted resource (Cambridge, 2017).

There are several combustion technologies that have been developed for energy recovery from MSW. About 80% of the WTE capacity in the world is based on the "grate combustion" technology, because its simplicity of operation. Providers of grate combustion furnaces guarantee over 8,000 hours of operation in a year, that is, over 90% plant availability (Coolsweep, 2012).

Incinerating waste is just one of many to recover its energy content. Whether the main reason for incineration is waste disposal or energy recovery it is a good way of handling both issues. Using waste as a source of fuel for incineration is different from oil and natural gas due to its difference in composition and calorific value.

1.1.8.1. Most worldwide calorific value of Waste.

It is usually a combination of industrial, domestic and agricultural waste, and the composition differs depending on what types of waste are available. The organic part in agricultural and municipal waste has a lower calorific value due to its high moisture content. Therefore the mixture of waste can have a range of calorific value from 5 MJ/kg to 15MJ/kg, while for example coal has a calorific value of around 25-30MJ/kg. The calorific value of paper is around 3.5-3.7MW/tone, food contains around 2 MWh/tone, plastic contain 8-10 MWh/tone while the average calorific value for combustible fuel used in reports by ANRE is just above 8 MWh/tone (Alvarez, 2006).

1.1.9. Heat recovery

The heat generated during incineration process escapes as flue gas at a temperature of approximately 1000-1200^{0}C. The flue is cooled in boiler where the heat is used to boil the water and convert them to steam. The flue is corrosive in nature and contains high levels of particulate matter.

1.1.9.1. Heat transfer efficiency factors

These factors are required for the two sections where thermal energy utilization takes place. Firstly, it is the heat exchanger where a part of the thermal energy of the produced synthesis gas is recovered. An efficiency factor equal to 0.8 has already been assumed in the development in many models on feasibility study of waste-to-energy power plants. As a result, the use of 0.8 appears to be a realistic value for the heat exchanger, and this value is used in this study, too. Secondly, it is the drying of sewage sludge. In this case, an energy consumption factor is required that will be used for calculation of the thermal energy consumed for drying a specific amount of sewage sludge **(**Cambridge, 2017).

1.1.10. Energy recovery

The steam that is generated by the boilers rotates the turbine due to high pressure and temperature. Through various stages, the velocity of the turbine shaft increases and results in the generation of electricity. Around 0.3-0.7 MWh energy is produced from incinerators while combusting 1 tonne of municipal solid waste. It depends on parameters such as calorific value of waste, plant size and steam parameters the process of waste-to-energy shown in Figure1.5 (Cambridge, 2017).

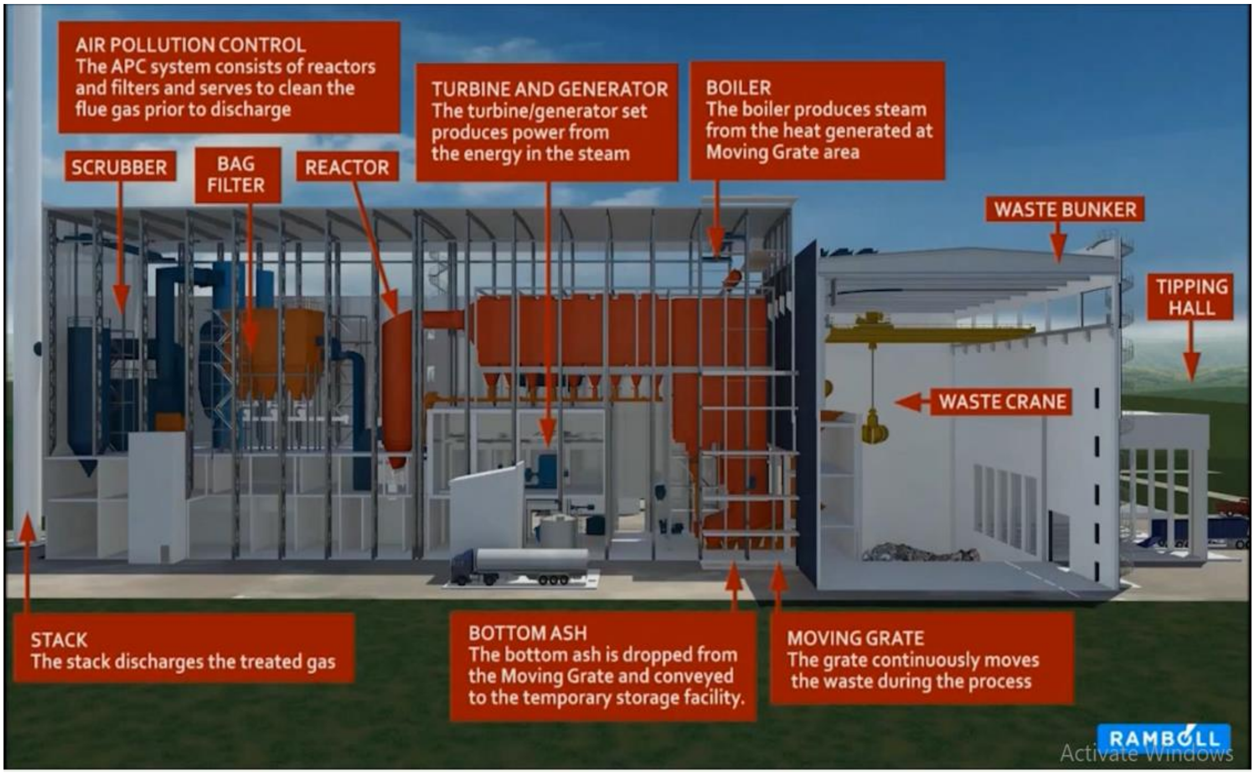

Figure 1. 5 The overall plant layout and description of some plant component (Haverd, 2010)

In order to have a better and more stable burning process, it was decided to install air heaters. The air heaters heat up air that is used in the furnace. The air is heated to 90^0c before it is fed into the combustion process. The maximum total energy used to heat up the air is approximately 650kW, which is about 4 percent of the total amount of energy produced on more advanced waste to energy power plant (Havard, 2010).

1.1.12. Steam boiler

The steam boiler is where the heat exchange between the flue gas and the boiler water takes place. The feed water is first exposed to the heat of the flue gas in an economizer before it is vaporized in an evaporator. The steam is the passed through a super heater increasing its temperature and by controlling this process one can get the desired steam properties, a simple steam boiler shown in Figure1.6 (Alvarez, 2006).

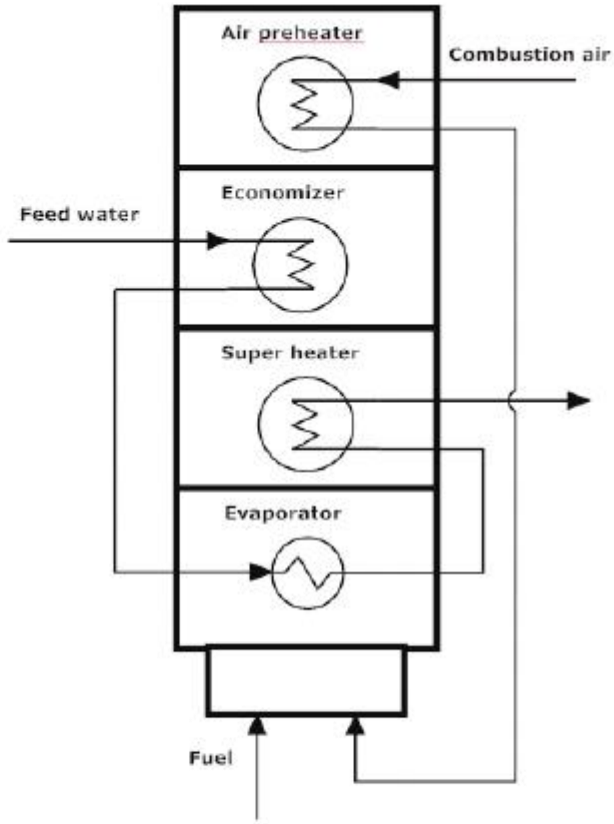

Figure 1. 6 Simple Steam boiler schematic (Alvarez, 2006)

Boilers for WTE power plants are typically water tube boilers, and most often they have four passes: three vertical radiation passes and a convective pass. The first radiation pass is integrated in the furnace (integrated boiler) as the post-combustion chamber. The convection pass, in which the evaporators, superheats, and economizers are located, may be vertical or horizontal.

Thus, as schematically shown in Figure 1.7, it is possible to differentiate three different heat surface areas:

- Economizer (feed water-preheating heat exchanger (HE); ECO in Figure1.7.): In this area, the boiler feed water is heated by flue gases to a temperature close to the boiling point.
- Evaporator (EVA in Figure 1.7); in this area, the water coming out from the economizer is heated until it reaches the saturated steam temperature (designed as a bundled heating surface, envelopment wall of the incineration chamber).
- Super heater (SH in Figure1.7); in this area, the saturated steam coming out from the evaporator is superheated to the maximum temperature. Spray coolers and surface coolers are used in circulation boilers in order to maintain the exact required steam temperature (Linus, &Tomas, 2012).

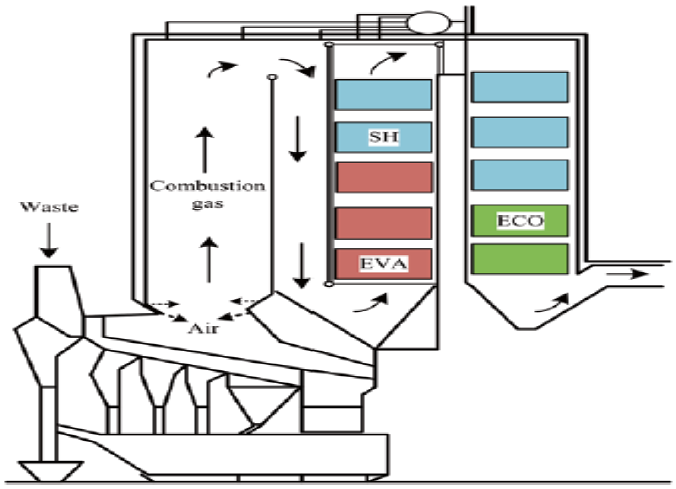

Figure 1. 7 Typical heat surface areas in a steam generator, SH superheating, EVA evaporation, ECO economizing (Lisa, 2015)

1.1.12.1. Steam Cycle

Based on a collection of waste-to-energy (WTE) facilities data, a “state-of-the-art “ WTE power plant is identified: Typical values of steam cycle pressures and temperatures are discussed with reference to the corrosion problem and characteristic plant size. Starting from the “state-of-the-art” WTE power plant, a sensitivity analysis is carried out to analyze the effects of the most important steam cycle parameters and configuration, improving the thermodynamic efficiency of the facility. An initial assessment of the importance of the main steam cycle parameters must be outlined as a preliminary study in order to understand the possibilities and the benefits of a thermodynamic cycle upgrade for a WTE power plant (Lisa**,** 2015).

The name combined heat and power plant (CHP) comes from the fact that the steam energy is used to produce electric power and hot water. The main source of energy in the obtained steam comes out of the condensation process. Extracting this energy can be done in different ways. Either the steam is run through a back pressure turbine where it condensate against the district heating grid or another pressurized water source. Otherwise a condensing turbine is used where a low pressure water source or a cooling tower is used to cool the steam. The steam is passed through one or more turbines, with intermediate super heaters in between them. Increased pressure and temperature in the process affect the obtained electrical power in relation to thermal power, but it also puts greater strain on the components of the plant. A temperature of 400^0c may cause high temperature corrosion and forces the boiler to have steel alloy super heater tubes to withstand the strain. Pressures below 40 bar lower the requirements for pretreatment of the feed water, the simple steam cycle schematic as shown below in Figure1.8 (Linus &Tomas, 2012).

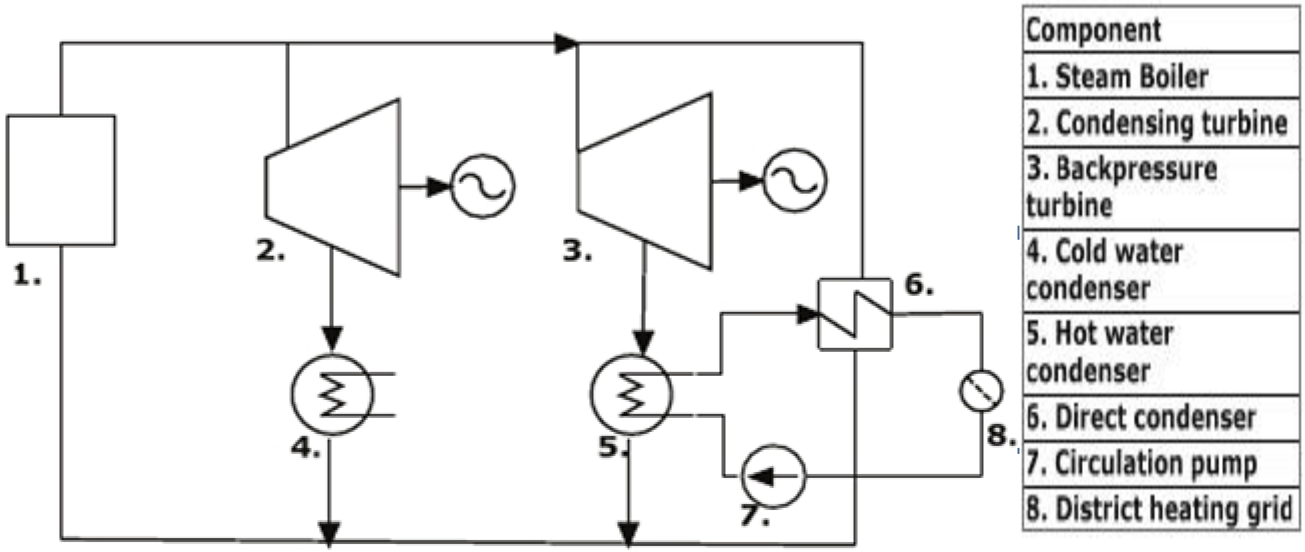

Figure 1. 8 Simple steam cycle schematic (Linderholm, 2012)

The amount of energy recovered from waste combustion can vary significantly with the characteristics of municipal solid waste (MSW) fed into the boiler (composition; mass flow rate; and lower heating value, LHV), the combustion technology, the configuration and features of the recovery boiler (adiabatic or integrated), and the characteristics of the thermodynamic cycle.

Rankine cycle

The Rankine cycle is a thermodynamic cycle describing one of the most common steam cycles. A thermodynamic cycle is when a system goes through a set of steps with heat or work exchange with the environment and then returns to its initial state. The Rankine cycle is used to theoretically determine the efficiency of a turbine system. The Rankine cycle may use different types of working fluid where water is the most common one (Alvarez, 2006).

The single Rankine cycle contains four different steps before returning to the initial state, see Figure1.9.

1. The cold working fluid in the initial state is pressurized at constant entropy.
2. The liquid is heated at constant pressure in the boiler by an external heat source. The outcome is saturated dry vapor.
3. The vapor is expanded at constant entropy over a turbine, generating electricity.
4. The steam is being condensed at a constant pressure to a cold liquid, ant the cycles is completed.

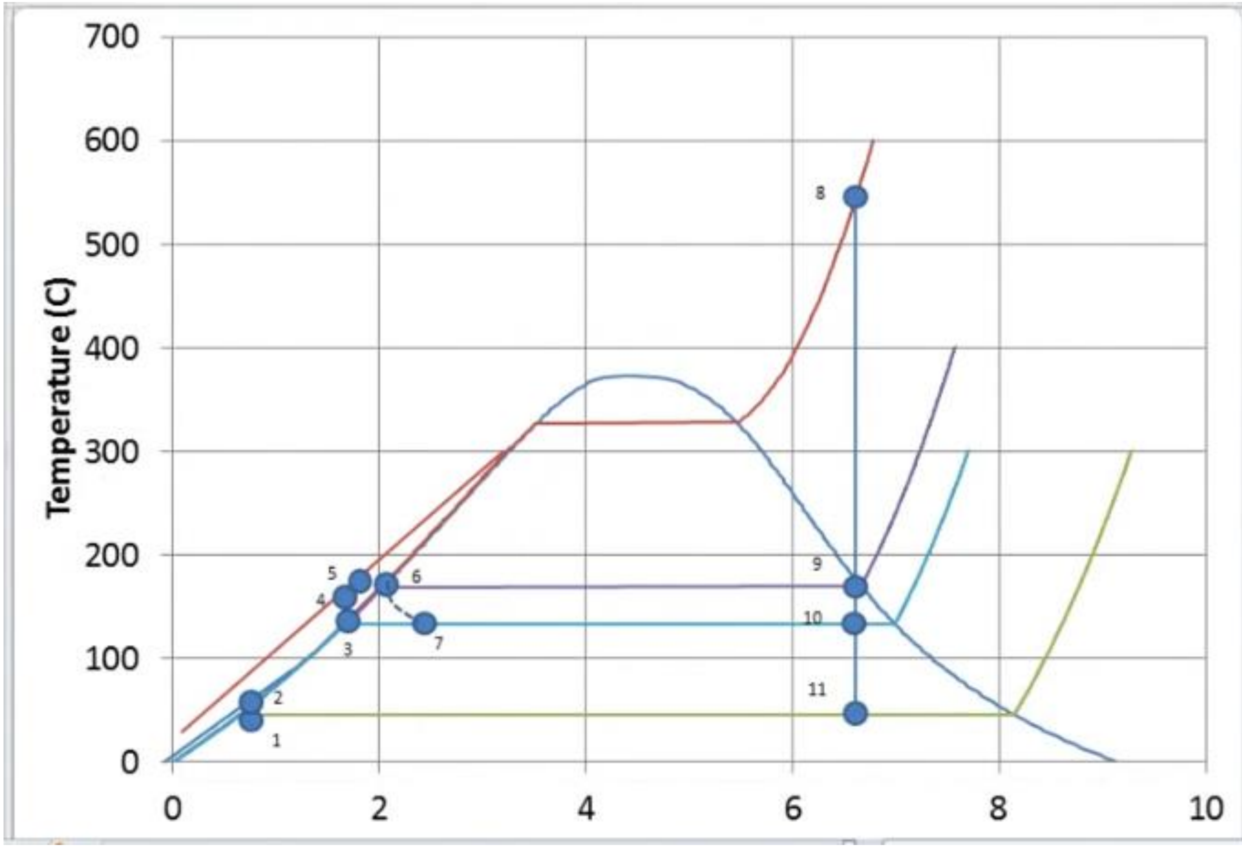

Figure 1. 9 TS-Diagram of the Rankine cycle (Lisa, 2012)

1.1.13. Flue gas cleaning

When the flue gas has exchanged the majority of its heat in the steam boiler, it has to be cleaned from pollutants that are produced during combustion. There are two types of pollutants in the flue gas: dust and gaseous emissions. Typical pollutants is dust from are fly ashes and heavy metals, while NO_x,SO_x and HCl are in gaseous from (European Commision, 2005).

The content of pollutions in the flue gas depends mainly on the waste composition, but also on the quality of the incineration process. To reduce emissions into the environment the flue gas has to be cleaned and treated. There are seven main groups of methods that are used for treating the flue gas from pollutions. These are: particle filters, dry treatment and semi-dry-treatment, wet treatment, NO_x treatment, powdered activated carbon injected, and bag filter (Alvarez, 2006).

1.1.14. Particles filters

Particle filters can be divided into four different types: cyclone, electrostatic precipitator, fabric filter and wet scrubber. The methods are described below and showed in Figure 1.10.

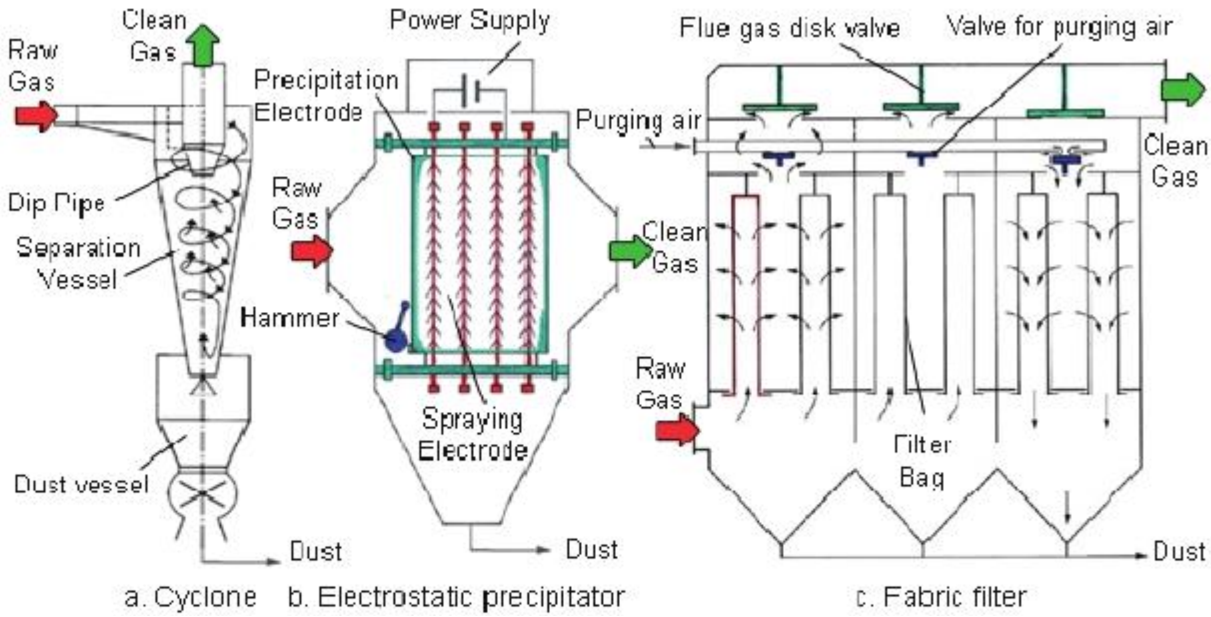

Figure 1. 10 Cyclone, Electrostatic precipitator, fabric filter (Linus and Toma, 2012)

1.1.15. Cyclones

In the cyclone the centrifugal force is used to separate out particles by forcing the flue gas in a circular motion and hitting the wall of the cyclone. The particles fall down and the flue gas is leaving the cyclone in the top (Linus &Tomas, 2012).

1.1.16. Electrostatic precipitator

In an electric filter the flue gas pass an electrically charged field. The voltage in the field gives the particles a negative charge. These negatively charged particles stick to a positively charged electrode, and is separated from the flue gas. This method is more effective than the cyclone method and it can also be used in an early stage since it is not dependent on the temperature (Alvarez, 2006).

1.1.17. Electro venturi filter

An electron venture filter is a wet electrostatic precipitator that instead of a positive electrode uses positive charged water molecules in a mist that entrap the negatively charged particles (Linus &Tomas, 2012).

1.1.18. Fabric filters

These filters consist of textile tubes where the flue gases can pass through, but where the dust particles are captured. When the textile tubes are full it can be cleaned by different methods like shaking, pulse jets and air blowing. The most common method is the pulse jet, where high pressure air forces the particle cake to release from the textile tube. When released it is dropped to the bottom of the filter house and gathered for further process. If activated carbon or lime is injected to the flue gas before the fabric filter the cleaning will be more effective (European Commission, 2006).

The raw flue gas from waste incineration contains a variety of substances that are toxic to the environment. The most common are HCl, SO_2, HF, dioxin, mercury and heavy metals. To reduce the content of these toxins, different treatment methods are used. The different methods can be divided in two groups, NO_x reduction and absorbent usage. There are three different main types that use absorbents to reduce the content of HCl, SO_2, dioxin, and mercury in the flue gas, dry semidry and wet treatment. The two main absorbents utilized are lime and activated carbon. Absorbents react with the toxins and the byproduct can be gathered in a particle filter (Linus &Tomas, 2012).

1.1.19. Dry treatment

The lime neutralizes and binds the gaseous acidic parts of the flue gas, such as sulphuric acid and hydrochloric acid, shown in equations 3-6. When passing a fabric filter the absorbed gaseous pollutions get stuck in the fabric filter. To improve the cleaning process activated carbon is added to the flue gas before the fabric filter. Dioxins and heavy metals bind to the activated carbon and get separated from the flue gas in the particle filter. Other dust pollutants also get separated in the fabric filter. Excess absorbents can be reused in the process. The dry residues from this method have to be stored safely on a controlled landfill (Alvarez, 2006).

$$Ca(OH)_2+SO_2 \rightleftharpoons CaSO_3+H_2O \quad (1.3)$$

$$Ca(OH)_2+SO_2 0.5O_2 \rightleftharpoons CaSO_4 + H_2O \quad (1.4)$$

$$Ca(OH)_2 + 2HCl \rightleftharpoons CaCl_2 + 2H_2O \quad (1.5)$$

$$Ca(OH)_2+2HFC \rightleftharpoons aF_2+2H_2O \quad (1.6)$$

1.1.20. Semi-dry treatment

The semidry treatment contains of a reactor that adds the absorbent as a slurry with water, to the flue gas and particle filter that's separate the toxins and absorbents from the flue gas. The heat in the flue gas vaporizes the water and the absorbents react with the toxins, Figure1.11.

$$Ca(OH)_2+SO_2(g) \rightleftharpoons CaSO_3(s) + H_2O(g) \quad (1.7)$$

$$Ca(OH)_2+2HCl(g) \rightleftharpoons CaCl_2+ 2H_2O(g) \quad (1.8)$$

$$Ca(OH)_2+2HgCl_2 \rightleftharpoons CaHgCl_2+2H_2O(g) \quad (1.9)$$

This method results with a dry residue that consists of the filter masses which must be safely deposited on regulated and controlled landfills (European Commission, 2006).

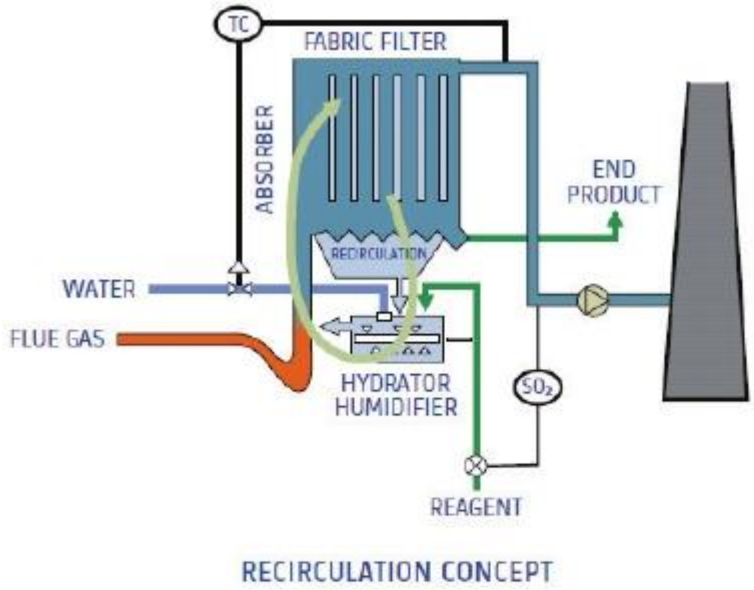

Figure 1. 11 Semidry treatment system (European Commission, 2006)

1.1.21. Powdered activated carbon injection

Powered Activated Carbon can absorb heavy metal and dioxins. The heavy metals in the flue gas, such as, mercury and thallium, and dioxins can be absorbed into the pore of the PAC, and form the small dust, which can be removed by the following bag filter also. Therefore, the PAC can deprive dioxins and ions pf heavy metal in the flue gas efficiently. The PAC will be injected after the semi-dry scrubber and before the beg filter (Bodenan et al., 2003).

1.1.22. Bag filters

The react between the acid gas and absorbent will generate solid particle (<µm), it will be very harmful to the environment. A bag filters are usually installed downstream of the process; they operate at least at 150^{0}C to avoid generating clogging [Bodenan et al., 2003].The fabric layer of the bag filter can absorb the particles with a diameter of smaller than macrons. Therefore, bag filters can remove heavy metals and dioxins with a high efficiency. Moreover, if the filter cake contains AC, the toxic organic pollutants, and heavy metals removal efficiency can be more than 99 wt% (Grieco et al., 2009).

1.1.23. Wet treatment

Wet treatment is a more advanced method than the dry treatment methods. In this method the flue gas is cleaned from pollutants in several steps which include different kind of wet scrubbers. If the flue gas contains a lot of dust particles a pre filters is used before the wet treatment. In the first step of the wet treatment the flue gas is cooled down to approximately 60^{0}C in the quencher. After the quencher the flue gas is passed to a wet scrubber which contains water with a low pH. In this scrubber HCl, HF, heavy metals and mercury are captured in the water solution. In the third step the pH is raised to a neutral level by adding lime. The SO_2 in the flue gas reacts during scrubbing with lime to from calcium sulphite, which after oxidization forms calcium sulphate and gypsumin the last step the flue gas is reheated, see Figure1.12 (Alvarez, 2006).

To clean the flue gas from dioxins it is passed through a fabric filter with activated carbon. The residue water from the wet treatment is contaminated and must be taken care of. The wet treatment can better handle flue gases with high content of sulphur compared to the dry treatment. The residues from the wet treatment are also easier to handle. On the other hand that wet treatment has a higher investment and operational cost (European Commission, 2006).

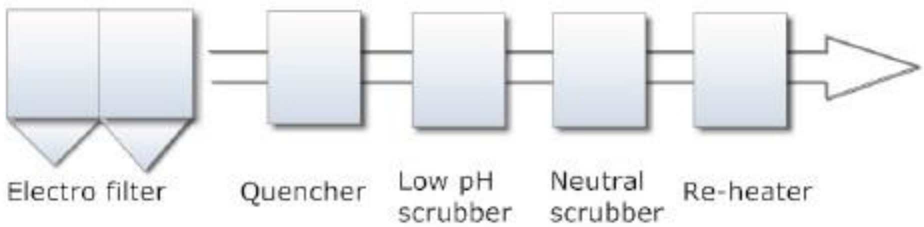

Figure 1. 12 Wet flue gas treatment steps (European Commission, 2006)

1.1.24. Air pollution Control

MSW contains a large number of chlorinate organic compound, it will lead to forming some toxic substance in the flue gas after the combustion process, such as dioxin. To reduce these volatile organic compounds, the project should keep the high combustion temperature (greater than 800^{0}C) and the retention time (longer than 2s) of MSW in the furnace. Moreover, the active carbon is used as adsorbent to remove dioxin and other toxic gas in most of WTE plants [Lu, 2005] NH_3 or urea can be utilized for NO_x removal based on selective non-catalytic reduction (SNCR) or selective catalytic reduction (SCR) (Jannelli et al., 2007).

In the SNCR process, the NH_3 or urea can be injected into furnace directly, due to the operating temperature can be higher than 850^{0}C. However, the operating temperature in SCR process is at the range between 200^{0}C and 400^{0}C. Otherwise, the catalysts will be deactivated in strong acid media. Therefore, the SCR process should be installed after baghouse, it will lead to the necessity of re-heat gas up, which cause the increasing of operating cost, a comparison between SNCR and SCR seen in Table1. 3. The emissions such as flue gases with particulate matter, acid gases such as hydrogen chloride, hydrogen fluoride, sulphur dioxide and heavy metals (mercury, cadmium and lead) are controlled using cyclones, bag filters, electrostatic precipitators, scrubbing, and absorption SCR processes (Margarida et al.,2011).

Table1. 3 Comparison between SNCR and SCR (Margarida et al, 2011)

Column1	SNCR	SCR
Advantage	Lower investment cost, lower corrosion problem	More efficient
Disadvantage	Limited efficiency	Higher investment cost, higher pressure drop requires higher O2 excess up to 85%

1.1.25. Feed pre-treatment drying system

Before feed waste in to the furnace it required treatment, a waste feed subsystem is used for pre-treatment of the waste in order to meet the inlet requirements of the gasification furnace. For sewage sludge, a waste material with high moisture content and a dryer for reducing the moisture content of the sludge will be required with airtight screw feeders being required to drive the sewage sludge into the furnace. Multiple ports ensure that the waste is evenly distributed within the furnace, and an airtight operation ensures that the reducing atmosphere of the furnace can be fully controlled and no synthesis gas can escape from the furnace to the local surroundings (Margarida, et al., 2011).

1.1.26. Sewage sludge from waste water treatment facilities

Sewage sludge treatment and disposal represents one of the most important issues for environmental management in Ethiopia. There is a challenge in changing the perception of sludge from an unwanted waste to a beneficial resource, and it is important to develop a suitable technology or use an existing one in order to reduce the environmental problem and costs to sludge treatment while, at the same time, utilizing it as a source of energy (Jannelli et al., 2007).

1.1.27. Sewage sludge properties

When looking the fact that sewage sludge is a waste material with a varying chemical composition and is not well defined, critical analysis of sewage sludge as well as experimental investigation of its heating value is required. The sewage sludge that is produced in Addis Ababa passes through an anaerobic digestion section and, then is mechanically de-watered prior to its final deposition In sewage sludge due to the higher percent of carbon and hydrogen, contains a greater amount of chemical energy as indicated by the greater value of the higher heating value (HHV) in comparison to the sample after the anaerobic digestion and production of methane gas.

1.1.28. Residues from waste incineration

The residues from the waste incineration are dross and flue gas cleaning residues such as: fly ash and particle cakes from different kind of filters. Where wet treatment is used, sludge is also a residue. The dross is produced from unburned particles in the combustion process. If a moving grate incinerator is used the weight of the dross can be up to 10-20% of the input waste. Sieved and sorted dross can be used in the construction industry as a complement to gravel. The dross can also be used in road construction and as a final cover on landfills. The disposal of dross needs to meet the local environmental regulations (Linus &Tomas, 2012).

The residues from the flue gas cleaning contain toxins and needs to be treated carefully. There are several techniques to make sure those dioxins and heavy metals in the residues not leak into the environment. A commonly used technology is solidification, where the residue is mixed with lime or cement to produce a solid mass is finally stored at sanitary landfills. The total residues from flue gas cleaning are around 3-5% of the total fuel weight, if the moving grate technology is used (European Commission, 2006).

1.1.29. Waste-to-energy ash reuse

The waste-to-energy facilities burn trash to generate electricity, Nearly 3 million tons of ash, or more than one-third of all residues, are reused annually as construction material, road aggregate, asphalt-mixture, and even in the construction of artificial reefs and cement blocks.

Waste-to-energy ash is tested to ensure it is non-hazardous. If metals leach in amounts greater than a fraction of 1%, the ash is considered hazardous. Years of testing ash from every waste-to-energy facility have proven that resultant ash is safe for reuse (Cambridge, 2017).

Test results and measurements taken in the field show that the levels of metals present in waste-to-energy ash leach rates are close to the significantly more restrictive drinking water standards and for lower than any toxicity criteria. Waste –to-energy ash represents about 5% of the volume of the trash processed. Ferrous metals are removed from the ash at the facility, leaving a residue that looks like wet cement. Waste-to-energy residue actually has physical properties similar to construction mixtures such as concrete after a short time, waste-to-energy ash ”cures” and resembles concrete (Linus &Tomas, 2012).

1.1.30. Water treatment

Contaminated water from the wet treatment has to be cleaned before it is discharged to the environment. This is done by the same technology used in municipal sewage treatment. In the first step of this technology precipitant and flocculants binds the heavy metals in the waste water. The flocculants are separated in sedimentation pools. Lastly the water is cleaned through sand filters and filters with activated carbon. The treatment concentrates almost all the pollutions in sludge which is processed as flue gas residues (European Commission, 2006).

1.1.31. Drying techniques

It is possible to improve the quality of solid fuels by increasing the share of dry substance during a drying process. In the drying process moisture in the fuel is evaporated and absorbed by a drying media, usually air, and steam of flue gas. By reducing the moisture content in the fuel the heating value increases (Berntsson & Wennberg, 2010).

Some advantages from drying solid fuels are (Berntsson & Wennberg, 2010).

- More heat produced per unit fuel because of a higher heating value.
- Higher yield of electricity per unit of fuel.
- Reduced flow of flue gas, since less moisture have to evaporate in the furnace.
- Increased temperature in the furnace, which improves the capacity of furnace where heat is transferred to the steam cycle.
- Possibility to use low quality heat, for example district heating, to gain primary energy in from of electricity.

There are several techniques used for a drying process. The quality of the drying fuel and heat source available for drying are parameters that decide the suitable drying technique. Some commonly used techniques are presented below.

Fluid bed dryer: in a fluid bed dryer particle fuel is dried in a pneumatic drying process. Flue gas, steam or heated air can be used as a drying medium. The drying technique is very effective but demands pre-treatment (Berntsson & Wennberg, 2010).

Bed dryer: in the bed dryer technique the solid fuel is placed on a moving bed. Heated air is blown through the bed of solid fuel to evaporate and absorb moisture. The air can be heated through a heat exchange from a low quality source, for example district heating. The final moisture level on the fuel vary depending on the flow of the fuel and heated air, the thickness of the solid fuel on the bed as well as the temperature of the heated air. The bed dryer has a relatively low electricity usage. The bed drying technique is explained in Figure 1.13.

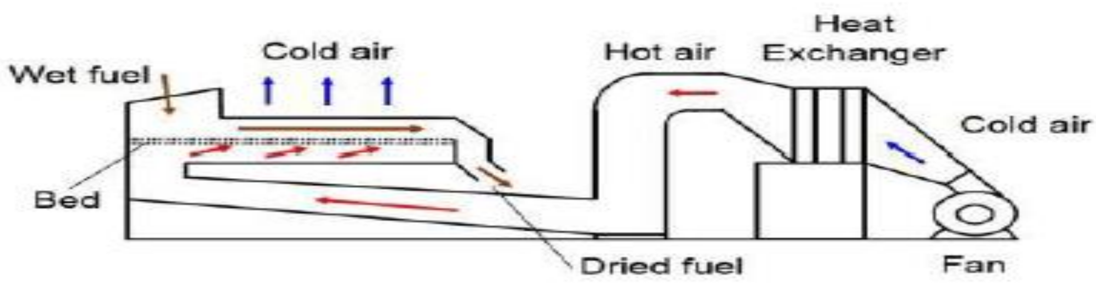

Figure 1. 13 Bed drying technique (Berntsson and Wennberg, 2010)

1.1.32. Waste separation and recycling

According to the waste-to-energy researchers at waste-to-energy plant has a world-class separation facility that identifies a set of materials that cannot be gasified (mostly metal) that will be sent to factories throughout the country to be recycled. The question of whether the recycling of these materials is valuable or not can only be answered if the recycling process is compared to production methods where the primary raw materials is utilized. Energy and material consumption associated with the recycling effort are taken into account for this exercise (Margarida et al.,2011).

To use a standard example, the separation and recycling of glass (although not actually possible in Ethiopia) could be questioned because the production of a new glass bottle out of used glass saves some raw materials but burdens the environment with the transport (emissions) of bringing the used bottle to a recycling center, sorting, pretreatment (energy input), and water consumption in the reprocessing of the used glass (Berntsson & Wennberg, 2010).

Under the best of circumstances, there is no doubt that the separate collection of ferrous metals, aluminum cans, glass and paper with subsequent recycling contributes to the protection of the natural resources and to reaching recycling targets. Due to absence of significant amounts of certain recycling streams and treatment facilities, however, Ethiopia is simply not in the position to leverage its full recycling potential (Cambridge, 2017).

1.1.33. Separation facility and selling inert materials for recycling

The study of waste-to-energy expert's shows as most of the collection of recyclable wastes in Addis Ababa is performed by the informal sector. The first "level" of source separation usually takes place at the household level. Plastic materials, glass and bottles are considered as valuable and usually sorted out for re-use (Mengsitu, 2014).

1.1.34. Environmental aspects of WTE

All energy production from power facilities generates emissions to air and water, as well as residues from unused fuel and fuel gas cleaning. To control the emissions from waste incineration plants the EU has set up the waste incineration Directives, WID. The maximum daily discharged emissions generated by waste incineration are specified in Table1.4 below (European Commission, 2006).

Table1. 4 Daily emission standards from Waste incineration Directive

Parameter	Unit	WID(Annex VI)
Total dust	mg/Nm^3	10
HCl	mg/Nm^4	10
TOC	mg/Nm^5	10
CO	mg/Nm^6	50
HF	mg/Nm^7	1
SO2 and SO3	mg/Nm^8	50
Sb+As+Pb+Cr+Cu+Mn+V+Ni+V	mg/Nm^9	0.5
Dioxins and furans	mg/Nm^10	0.1
Nox	mg/Nm^11	200

1.1.35. CDM assessment on waste-to-energy plant

A deep assessment of the clean Development Mechanism (CDM) has been carried out in order to evaluate the institutional and regulatory framework of CDM in Ethiopia as well as the opportunities to register the plant plasma gasification project as CDM activity. Furthermore, the potential amount of annual Certified Emission Reduction (CER) credits to be generated by the waste-to-energy facility must be calculated. Under the Kyoto protocol, the Clean Development Mechanism (CDM) is a method of emissions trading that allows for the generation of tradable credits (Certified Emission Reductions (CERs)) for greenhouse gas emissions reductions achieved in developing countries, which are then purchased by developed countries and applied toward their reduction targets. CERs are also accepted as compliance tool in the European Union Emissions Trading Scheme (Cambridge, 2017).

1.1.36. Produce clean renewable energy from waste-to-energy power plant

Unlike other types of renewable energy resources, waste-to-energy is considered a base load power that operates 24 hours per day, 365 days per year. As a result, these facilities reliably generate approximately 17 billion kilowatt hours of electricity per year-enough to power approximately 2 million American homes. This accounts for nearly 20 percent of all renewable electricity generation in the United States and is 4 times the amount of energy produced in all of Ethiopia in 2011. The impact to global warming from different greenhouse gases can be measured by a Global-warming potential, GWP index, and see Table 1.5. This index compares how much heat a certain mass of greenhouse gas traps in the atmosphere relative to the same amount of carbon dioxide, hence carbon dioxide have the GWP value 1. The GWP value depends on the absorption of infrared radiation by a given gas and its residence time in the atmosphere. The GWP index is calculated over different time intervals, usually 20, 100 and 500 years. In this report the GWP value for 100 years will be used (Linus, et al., 2012).

Table1. 5 GWP 100 values IIPC, 2007

GAS	GWP 100
Carbon	1
Methane	25

1.1.37. Economical views

There are different kinds of investment calculations to determine if an investment is financially viable or not. In this paper the payback time and the net present value, NPV, models are used. These two models are among the most commonly used methods by businesses. To be able calculated these models the investment cost and annual cash flow from the different plants has to be estimated (Gavelin and sjoberg, 2012).

1.1.38. Payback

The payback method calculates the time it takes for an investment to be recovered based on its annual profits. The payback time of an investment is important when determining whether to proceed with a project or not. If an investment has a longer payback time then the lifetime of the investment it is not a profitable investment. A short payback time is desirable. The payback time is calculated by dividing the investment cost with the annual cash flow as shown by Equation 1.10 (Gavelin & sjoberg, 2012).

$$payback\ time = \frac{investment\ cost}{annual\ cash\ flow} \quad (1.10)$$

1.1.39. Net present value

The net present value method, NPV, determines the present value of an investment by the discounted sum of cash flows received from the project during the investments estimated lifespan Equation 4. A zero net present value means that the project will repay the investment cost plus a required rate of return. When the net present value is zero the rate of return is called internal rate of return, IRR. If the net present value is positive it means that the investment is financial viable. A negative net present value means that the project won't be profitable in comparison to another investment with the stated rate of return (Gavelin & sjoberg, 2012).

$$NPV = \sum_{t=1}^{T} \frac{Ci}{(1-r)^t} - CO \quad (1.11)$$

Where

NPV= Net Present value

Co= initial investment cost

T=Estimated lifetime of investment

r=discount rate/rate of return

Ci=Annual cash flow

1.2. Statement of problem

Adama has so many problems as developing city one of the city's key problem is solid waste management. The Population of Adama is increasing from time to time and showing impressive economic growth trend. With this population increase and economic growth, the municipal solid waste is highly increasing. The way municipal solid waste of Adama currently managed is becoming challenging with a big landfill laid in 14,000m^2 with 1-meter depth (based on 2004 data).

This challenge of waste management system in turn prompts to look for different alternatives, how to manage and utilize waste with consideration to the environment. One of the alternatives to manage and utilize waste is energy recovery possibilities from municipal solid waste in Adama. That is why this paper deal with the feasibility studies of solid waste-to-energy: therefore, this makes important that Adama city municipal solid waste has to be managed effectively with possibility for energy recovery, Figure1.14 shows how look like the Adama waste deposited.

Figure 1. 14 Waste disposal site Adama city

The city Administration of Adama considers waste management to be a major priority and is eager to address this chronic issue in the city. The Administration of Adama should work with various groups within the Ethiopian Government as a holistic waste management company dedicated to providing innovative solutions to Adama, because the major difficulty of waste to energy is luck of proper waste management.

In conjunction with the existing waste management products and disposal mechanisms the Administration of Adama should work with organized waste collecting enterprise in order to introduce a waste collection system and a disposal mechanism that converts waste to energy.

In order to accomplish a permanent platform to keep Adama clean and beautiful it is vital to create an institutionalized system of waste management. Administration of Adama work in collaboration with manufacturing industry to help small enterprise by created modern waste collecting equipment to collect garbage throughout the city.

1.3. Objectives of the study

The primary purpose of this study is to assess the potential energy extraction from solar assisted solid waste for produce electricity in Adama city with the following objectives:

1. Decreasing the amount of landfill deposited waste
2. Decreasing energy dependence by providing an energy generation system with a reliable source of fuel.
3. Reducing the emission of greenhouse gases

In order for Adama to meet clean and attractive city, all unmonitored waste landfill activities must stop. A waste to energy solution is a way of dealing with this waste problem. As a result it is also contributing to the solution of the energy dependence problem. The selection of technology will be based on the local conditions of the study area. This will help to develop a solid waste management system of Adama, Ethiopia that will be environmentally effective, economically affordable and socially acceptable. In addition, this will ensure a better quality of life of present and future generations

1.3.1.Specific objectives

- Evaluate the feasibility study of waste-to-energy power plants for Adama.
- To identify the energy content of solid waste that collect in different sectors in the town.
- To examine how much energy can be extracted in a form of heat and electric energy.
- Select or design the appropriate boiler.
- Select or design the suitable turbine.

1.4. Significance of the study

This study is very important to know the city waste material energy capacity, environmental protecting and recycling some materials that generate in the city waste. While some still confuse modern waste-to-energy plants with incinerators of the past, the environmental performance of the industry is globally recognized as being beyond reproach. Waste-to-Energy plants, with their clean green emissions standards, actually reduce the amount of GHGs that enter the atmosphere when one compares to alternative waste disposal options or even the production of an equivalent amount of power from traditional technologies. Moreover, studies have shown that communities that employ waste-to-energy technology have higher recycling rates than communities that do not utilize waste-to-energy. The recovery of ferrous and non- ferrous metals from waste-to-energy plants for recycling is strong and growing each year.

1.5. Limitation of the project

Waste to energy (WTE) includes a number of different technologies for waste treatment with energy recovery, like incineration, gasification and pyrolysis. This study will only regard the incineration part of WTE. The two incineration technologies considered are the moving grate and the fluidized bed types. The different technology solutions might need separation of available waste. This study will not investigate how this separation can be performed. The different choices of components in the plant will be chosen with help from experts from WTE project managing companies.

According to Mengsti, the annual available mass of waste is estimated to be about 50,000 tons the waste materials taken into consideration are mainly waste from households and industries. In case that this amount of waste cannot be provided at a given time, it can temporarily be compensated for by the yearly surplus of straw from the agriculture sector. This means that there are reserves of fuel to cover potential differences between the supply and demand in incoming waste.

In the environmental comparison, the emissions of volatile organic compounds (VOC), toxic organic compounds (TOC) and metal oxides will not be studied as closely as the emissions of greenhouse gases (GHG), due to some inconclusiveness in the waste composition data.

In the design, due to the project time frame, no detailed calculations have been done on grid connection, cooling tower technology and means of waste accumulation.

In the economical calculations all investment casts have not been included, connection to the grid and pipe lines for district cooling are not included.

CHAPTER TWO
LITERATURE REVIEW

Hailemariam, (2014) studied solid waste management in Adama, Ethiopia: aspects and challenges, in this study he attempts to describe the aspects of solid waste management (SWM) in Adama, one of the fast urbanizing cities in Ethiopia, and highlights and challenges thereof. Data were gathered through interview supplemented by field observation and self-administered questionnaire. Then the data were analyzed using the Statistical package for social Science (SPSS) software. In addition, secondary data were gathered from documents. Findings revealed that current SWM practice couldn't cope with the fast urbanizing needs and the rapid population growth exhibited by the city. Besides, major factors contributing to the inefficient system were identified. The study would provide practical insights to decision makers in developing a sustainable SWM system leading to minimized risk in the city.

Asgedom, (2017) studied energy recovery possibilities from municipal solid waste (MSW) in Addis Ababa, Ethiopia. In this paper he analyses the challenges on MSW management faced by Addis Ababa city. The population of Addis Ababa increasing from time to time and the city is showing impressive economic growth trends as well. With this population increase and economic growth, the municipal solid waste of the city is highly increasing. With the objective of solving this challenge of municipal solid waste management, relevant literature is reviewed, and three different scenarios are made for future situation which estimates the potential of energy (electricity) recovery to reduce the quantity of MSW in Addis Ababa. Scenario 1 analyzed "Biological and Mechanical Treatment (BMT) of MSW" which is a combination of refuse derived fuel (RDF) and anaerobic digestion (AD) with potential of 11.76 MW and 9.80 MW electricity respectively. Scenario 2 "Mass incineration in grate fired furnace" produced a potential energy of 37.41MW electricity. Scenario 3 " landfill gas production from MSW" produced an estimated energy potential of 1.12 MW electricity. As a result of the evaluation and analysis of these scenarios, mass incineration in grate fired furnace (scenario 2) offered the highest potential energy of 37.41 MW electricity of the three scenarios.

Cambridge, et al., (2017) studied the feasibility study of waste to energy for Addis Ababa city, Ethiopia, done by with a collaboration of Ethiopian Electric Power Cooperation (EEPCo), unlike other feasibility study this one done by a Team researcher that joins with three organizations. The first African waste-to-energy established in Addis Ababa known as Rappi (koshe) waste-to-energy plant. The feasibility study presents and examines an innovative project, a plasma gasification waste-to-energy plant located at the Rappi (Koshe) landfill site that is based on a cutting-edge and thoroughly proven technology from Cambridge Industries. The project, representing a joint effort among the Ethiopian Government, Addis Ababa city Administration, EEPCo and Cambridge Industries, will place Ethiopia at the forefront of the green energy technological revolution with the first plasma gasification waste-to-energy plant in Africa.

The Team researcher suggests Rappi project will result not only in more energy for the grid, but in the reduction of the landfill, the creation of thousands of new jobs, and the beautification of Addis Ababa. The Team also study Renewable energy proposed capacity in Ethiopia, according to them for some time the Ethiopian Government, and has demonstrated the courage and foresight to address the challenges posed by climate change and the need to balance environmental protection with the requirements of a quickly growing economy and population. The country's Green Resilient Economy initiative embraces the need not only to meet these challenge head on, but also to do so in part by implementing new technologies that are particularly well suited to the Ethiopian dynamic.

Addis Ababa waste composition, the feasibility study Team, in collaboration with the city Addis Ababa, has collected various samples from the Rappi (Koshe) landfill site as well as various collection points throughout the city. The summary of the Team's findings are listed. City population 3,035,138, City total area is 540 square kilometer (54,000 hectare), average daily waste per household: 2.1 kg, average daily waste per person: 0.46kg, More than 200,000 tons are collected per day, the municipality has increased the collection rate from 60% to 80%, the primary collection is done by micro and small enterprises.

The feasibility study Team found the following with respect to waste collection in Addis Ababa:

1. In each zone micro and small scale Enterprise (MSE) is assigned to work on waste collection
2. The city is divided in to 549 zones, each zone comprising 800-1000 households
3. The number of enterprises organized to work on solid waste collection is 520, with a total number of 5815 operators
4. Most residents are willing to cooperate with the Government in financing solid waste management

The researcher of the feasibility study done there waste values assessment by using the similarity of known calorific value which is (8000-11000 MJ/ton) and the calculation of the theoretical energy potential is based on the amount of 200,000 tons of MSW including waste similar to that generated from the commercial and industrial sectors and with an average calorific value of 9500 ml/t^10. From this the feasibility of Rappi can produce 51.2MW thermal power for the main grid.

51.2 MW is the thermal power embedded in the waste and available for the production of electricity and heat, the following calculation highlights the electricity production using this thermal power in a Cambridge gas turbine. The calculation indicates that there is huge energy potential in the waste which is 185.68 GWh per year that is lost to landfill at present.

Emma, (2009) studied modeling waste to energy systems in Kumasi, Ghana. In this paper focus on the comparison benefits and environmental impacts between incineration, anaerobic digestion and landfill with gas collection as methods of solid waste management. All of these systems were assumed to generate electricity. To compare the different systems, a software model was created in MATLAB, Simulink. The study area was the city of Kumasi, the second largest city in Ghana with a population of more than 1.9 million citizens. The metropolitan area of Kumasi generates about 1100 ton of solid waste per day. It is assumed that 70% of the waste produced is collected. The rest of the solid waste is indiscriminately dumped in rivers or drainage systems burned. Today, the collected waste is brought to the landfill in the outskirts of the city. The results from the modeling were that the incineration scenario generated most electricity 191000 MWh/year, the anaerobic digestion system generated 37800 MWh/year and the landfill with gas collection system 24800 MWh/year.

Darmawan, et al.,(2013) studied feasibility of recovering energy from municipal solid waste to generate electricity in Indonesia. In this research tell as the municipal solid waste (MSW) disposal problem can be solved by applying an appropriate technology that can reduce the volume of the waste effectively and efficiently. Waste-to-Energy (WTE), or Energy-from-waste (EFW), is one of the most effective and efficient technologies for reducing the waste volume. This paper also deals the survey and investigation of waste characteristics, including waste composition, chemical and physical composition, and heating value, was carried out for typical Bandung MSW. According to this paper the Indonesian average heating value of waste is 1500kcal/kg can be expected from pre-treated MSW to be used as a fuel for direct combustion in a WTE plant. A typical design for a small- scale WTE plant is shown in this paper and also an energy analysis is provided. Approximately 800KW of electric power can be generated from 50 tons of MSW per day.

Abdul, (2011) have studied the feasibility of waste-to-energy recovery technologies in Lahore, Pakistan. In this study he showed as the quantity of solid waste in towns of Lahore is estimated multiplying the common factor by increased population but in not correlated with economic levels of different groups. The average estimated composition of Lahore solid waste was consisted of approximately 6.7% recyclables, 28% inert and 56% organic fractions. Current composition and quantity of solid waste is favorable for various types of waste-to-energy technologies. He concluded Lahore waste management company using the different common factors each year 0.65 ton/person/day are the average waste generation in Lahore. Landfill gas production and utilization and mass burn incineration are standalone most feasible technologies at first and second portion respectively for treatment of solid waste in Lahore. It is because: these two facilities have enough capacities (i.e., maximum worldwide operating capacities in range from 2 million tons to 2,850 million tons year for landfills and 750,000 tons/year for mass burn incineration) to treat the current generated waste at lower costs per ton (i.e., cost varies is in range from 3.55$/ton to 6.73$/ton, if waste quantity is in range from 2740 to 192 tons/day for landfill and 65$/ton to 85$ton,if quantity waste is in range from 1500 to 400 tons/day for mass burn incineration).

Jan and Anita, (2013) did waste-to-energy feasibility report, in this report they studied Drankenstein waste management and WTE. In waste management they investigate minimization and recycling goals of waste of Drankenstein local municipality (DLM). The report was divided in three scenarios in order to estimate the energy production (DLM) waste. The best scenario according to the study was 4/phase 3 with the Direct Combustion (DC) plant in operation, be able to produce green electricity of 12.1MWh which, after subtraction of the parasitic load, could make 10.67MWh available.

Tosin, et al., (2017) studied state-level assessment of the waste-to-energy potential (via incineration) of municipal solid waste in Nigeria. In this report they showed the overall the Nigerian waste energy content. They findings show that the electricity generation potential for the different states in Nigeria varied from 31-205MW, depending on state's waste generation capacity. The country's annual electricity generation potential from MSW was estimated to be 26744GWh/year, with 89% of the states having sufficient generation capacity at minimum regulatory electricity generation requirement of 50MW. However, based on current realities such as poor collection efficiencies, Nigeria's exploitable WTE capacity from MSW was below 3800GWh/year, with all the states having less than 50MW capacity.

Aman, (2017) investigated waste-to-energy and recycling in Urban India, in this research paper he showed that the advantage and disadvantage of incineration-based waste-to-energy technologies. According to his study the incineration technology require a continuous supply of waste inputs of sufficient quantity and quality, high calorific value and low moisture content to be viable. In India the government and industry proponents suggest that WTE and recycling are compatible systems of managing waste while their critics disagree. In this research paper also argues two main points. First, the government's preference for WTE contradicts the empirical evidence, which suggests that the physical, chemical and biological characteristics of Indian waste render it technically unsuitable for incineration. Second to be viable, WTE technologies will require end-to-end control over the entire waste management chain, thus displacing those in informal recycling sector from their mean of subsistence. Finally he concludes recycling is preferred over incineration (with or without energy recovery), however the problem is that recycling alone does not address the problem of what to do with other waste, particularly biodegradable waste that forms the largest component of Indian waste. Most government agency reports that concluded incineration was unsuitable for Indian waste, also suggested that composting was the most appropriate solution

Johan and Jon, (2015) studied pre-feasibility study on suitable Waste-to-Energy techniques in the Kutai Kartanegara region. In this paper the research data was collected during a two month long field study in Tenggarong the capital of Kurtai Kartanegara. From the collected data, various waste-to-energy systems and collection areas were simulated in Matlab. The thesis results from the simulations show that a system using both a waste incineration and biogas plant would be the best solution for the region. They have chosen system were designed to handle a total of 250,000 tons of waste annually collected from Tenggarong and neighboring districts. The system will provide between 155 and 200 GWh electricity and between 207 and 314 GWh of excess heat energy annually. Some of this is used in a district heating system with an absorption-cooling machine. The system investment cost is around 42.5MUSD and it is expected to generate an annual profit of 16MUSD. The thesis recommended solution will decrease the emissions CO_2-equivalents compared to the current waste system and fossil electricity production with 50%. The research results in the study clearly show that there are both economic and environmental potential for waste-to-energy technologies in the region. But the waste management and infrastructure has to be improved to be able to utilize these technologies.

Linus and Tomas, (2012**),** they did a pre-feasibility study of Waste-to-Energy plant in Chisinau, Moldova. This thesis worked on cooperation between the municipalities Borlange in Sweden and Chisinau in Moldova. The project aimed to explore the region's economic and environmental opportunities for waste incineration with energy recovery, also known as Waste to Energy. The method of the research has been done in three steps: the first one was gathering conditions for a WTE plant in Chisinau:- those are waste management and composition, Energy prices, Possible locations for a plant, Connection to heat and electricity grid, Emission regulations, and Efficiency of current energy producing plants. The second one analyzing gathered data using Swedish WTE expertise. They guided consultations come from Borlange Energi, and literature EcoEnergy, and Siemens Turbo Machinery and Alstom power Sweden to choose the following, incineration technology, number and size of boilers, Turbine and generators, Flue gas treatment, cooling tower, NOx reduction and Treatment of ashes and residues. Thesis results that show implementation of a waste incineration plant in the Chisinau energy system is economically and environmentally feasible, given the current conditions. The proposed plant is designed to annually handle 400,000 tonnes of waste, and would with the assumed waste composition deliver 560 GWh of district heat and 260 GWh of electric energy. This production provides an annual profit of 31.6 million Euro, Which gives as positive net present value after the project amortization.

Selva, (2017) done pre-feasibility study of a waste-to-energy plant in Santiago, Chile. According to Selva C**.** the Chile community there is much misinformation regarding the energy recovery technologies that are widely used in developed countries. This is unfortunate as the familiar old incinerators that were known for their high pollution and environmental impact. The new framework Law on the Management of Waste that entered into force in June 2016, known as extended producer Responsibility, aims to reduce landfilling and increase recycling rates. Based on different recycling targets, it is estimated that this proposed 3-line facility could process up to 1 million tons per year. This would reduce by 60% the waste generated in the Metropolitan Region that otherwise would be buried in landfills, assuming the most ambitious recycling scenario of 40%. Analysis the cost-benefit of building a Waste-to-Energy facility in Santiago was conducted, and the capital cost was estimated to be $305MM. This facility would be privately owned, with a capital structure of 20% equity and 80% debt, paid at a 5% interest rate for 10 years. This project has been proven to be feasible with a NPV of $31MM and an IRR of

11.76%, based on reasonable expenses and less-than –favorable assumptions; potential profit streams such as carbon credits, metals recovery, and lower transportation costs have been ignored. It was determined that this project remains profitable up to a capital cost of $337 per ton of annual capacity. In addition, analysis of NPV was conducted for different electricity prices and gate fees, resulting in break-even points of $42/MWh for electricity, and $13.5 per ton for gate year of 903,000 tons is required, with a minimum heating value of 7.3 MJ/kg, in order to make the project profitable. Recommended maintaining an updated database in order to make accurate estimations regarding waste management, this information should include, among other things: amount of waste generation per municipality annually, and costs of collection, transportation and disposal. In addition with the new initiatives, it will be essential to have a record of recycling and composting rates. He final recommended that a more detailed study of the ideal location of this plant be made considering several parameters crucial to its construction. As an example a 10 hectares plot that complies with the necessary regulations, that is in the vicinity of an in-service substation, and that minimize total transportation costs, would be optimal.

Perinaz, (2007) studied feasibility analysis of waste- to-energy as a key component of integrated solid waste management in Mumbai, India. On his research paper show that the solid waste management process in Mumbai, from generation to final disposal, and determine whether waste-to-energy is suitable method rather than waste disposal for the city. He examine various criteria are covered, such as the appropriateness of Mumbai's MSW for incineration, the environmental effects of WTE versus open dumping, the savings in availability and cost of land, in addition the amount of energy production from a waste-to-energy facility. Study the heating value of MSW in Mumbai, it is important to calculate the potential energy production from a waste-to-energy facility in order to assess how much energy, in the form of electricity and/or heating, can be created and sold. Although the municipal corporation of greater Mumbai (MCGM) reports that the average heating value is 3,898kJ/kg, this report calculated that the average LHV is 9,022kJ/kg, based on the values of energy content of MSW components given in Tchobanoglous (1993). Examine the moisture content of MSW in Mumbai is approximately 50% during the dry season and 65% during the monsoons. Generally, MSW with moisture content greater than 50% is not suitable for incineration. However, the compaction of MSW that will take place at transfer stations after they are modernized will decrease the decrease the moisture content of the MSW by approximately 20%. This will result in a moisture content of approximately 30% during the dry season and 45% during the monsoons, which makes the MSW suitable for combustion. Estimated for the purposes of his study, an area of 6 ha (0.06km^2) for a WTE facility in Mumbai. This value was chosen based on a survey of approximately 20 WTE facilities and their daily capacities around the world.

Siddharth and M.P. Sharma, (2017**)** investigation of feasibility study of power generation from municipal solid waste of Haridwar city in India. In this paper compare two leading innovative mechanisms of waste disposal being adopted in India are –composting (aerobic composting and vermin-composting) and waste-to-energy (WTE) (incineration, pelletisation, biomethanation). According to this paper WTE projects for disposals of MSW are a relatively new concept in India and in this paper suggest such kind of plant have positive results for developed countries. Haridwar city generate about 190 Tons of MSW per day. The main sources of MSW are domestic, shops and commercial establishments, hotels, restaurants, vegetable markets. Siddharth and M.P. Sharma examine the characterization of MSW samples were analyzed for its constituents manually by sorting/segregation before and after drying in shadow. Samples are collected from various location of dumping site. The physical and chemical analysis was conducted as per standard methods. The results show that fixed carbon and volatile matter 17% and 21% respectively with 20.5% moisture contents and 41% ash contents. Looking at 21% moisture contents, the resource appear to be suitable for biological process where moisture removal is not required. The MSW of Haridwar city is chemically analyzed in institute's laboratory. Various analyses such as proximate analysis and TGA/DTA analysis has been done to check the chemical properties of MSW and it is suggested that the biomethanation is the best technology for energy conversion.

2.1. Conclusion of literature review

From literature provide that waste is no more a problem for us, if use properly managed waste it will give so many benefits. The first benefits for waste is environmental protection, second it provide energy from it, thirdly from waste it provide for us economic benefit, which is during production of energy and earlier separation it provide that source of metal, this is so important for Ethiopia because we import metal from outside country.

When look the data collecting method, by taking sample waste that generated in municipality and burn in order to know the calorific value. Rappi feasibility study under investigated by Cambridge industry and Ethiopian Electric power Cooperation (EEPCo) they toke waste sample that generated in Addis Ababa and burn to know the calorific value, the sample taken 130,000 tons of waste could be utilized in a waste to energy facility. The essential component to consider is the bulky waste fraction with a calorific value similar to or higher than MSW (8,000-11,000 MJ/ton).

The second data collecting method to analyze the energy production of solid waste was the assumption method which is by assuming waste composition and elemental analysis done by other waste to energy facility and literature review or data of most solid waste characteristics.

Energy production technique most of feasibility study of waste-to-energy choose incineration type of energy production, because it handle a massive solid waste at once and provide good productions of energy. As we see in literature review the feasibility study of waste-to-energy by (Linus and Tomas, 2012) they choose incineration type to handle 400,000 tones of waste and produced 260GWh electricity. Also when see the first African waste-to-energy feasibility study, they also choose incineration to handle 200,000 tones of waste to produce 185.6GWh of electricity. So for energy production it best to choose incineration type of waste-to-energy power plant.

In most feasibility study of waste-to-energy power plant the calculation is based on steam cycle simulation, like when we see (Linus and Tomas, 2012) they used the principle of Rankine steam cycle mode, and steam simulation done on MATLAB software to analyze and calculate the power output of the plant. The steam cycle also mode in MATLAB software, shown in Figure 2.1 and 2.2 (Johon and Torstensson, 2015) they calculate the energy content by using of Rankine principle steam simulation done on MATLAB and SIMULINK under the help of ORWARE model. Like the first African waste-to-energy power plant the energy calculation mode by direct measure the waste calorific value by burning waste in the laboratory, but this kind of measurement at student level not possible. So energy calculation by using Rankine steam cycle principle is possible to determine the waste energy content.

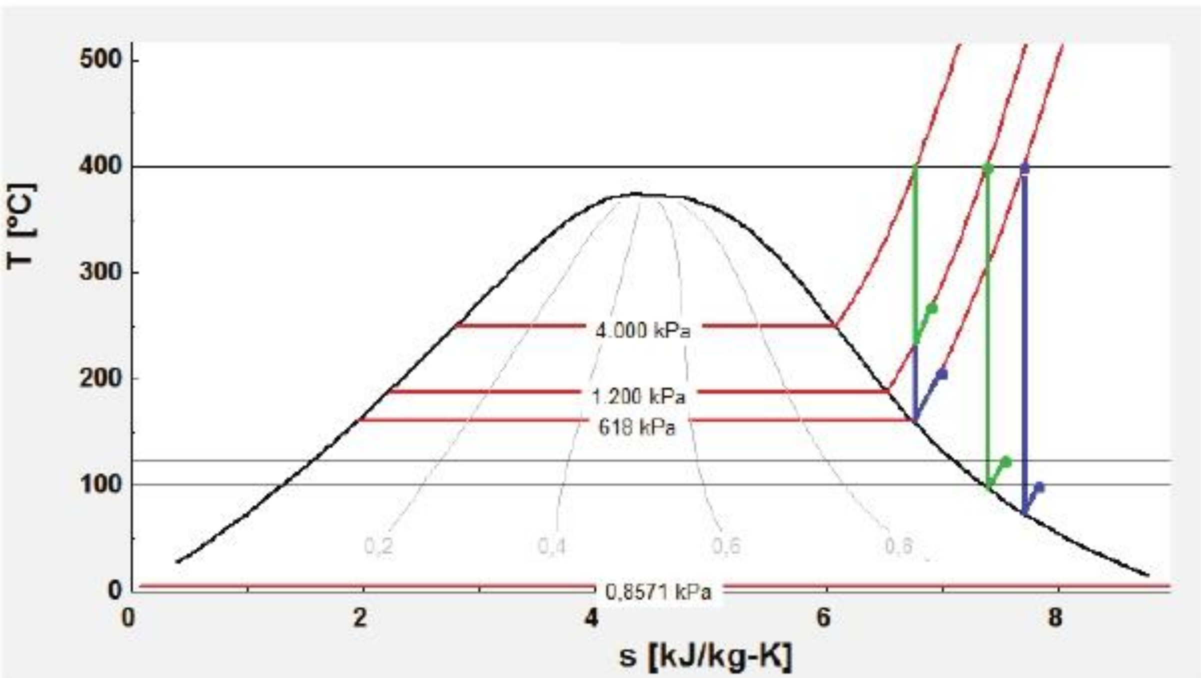

Figure2. 1Rankine cycle (Linus and Tomas, 2012)

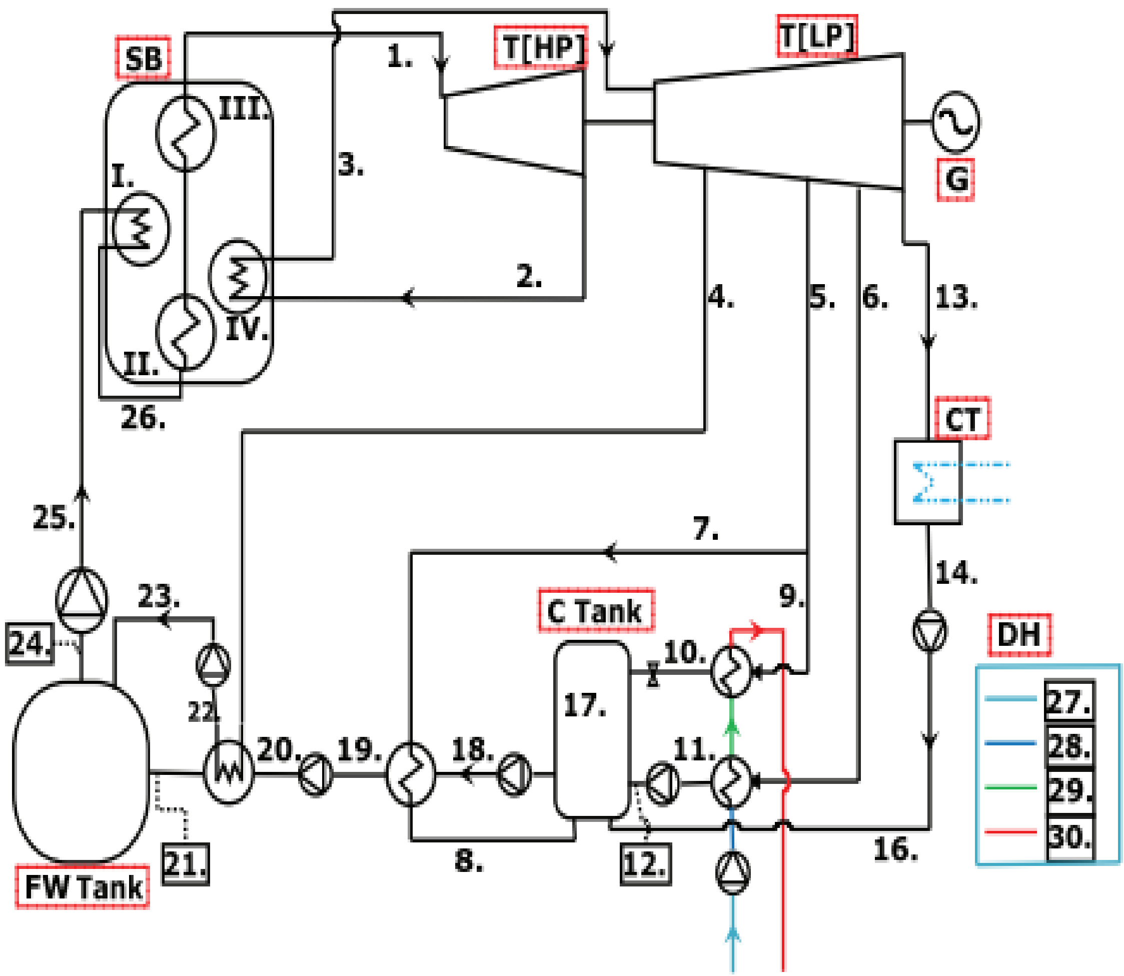

Figure2. 2 steam cycle model in MATLAB (Linus and Tomas, 2012)

Finally it is possible to concluding suitable plant dimensions and estimation of economic and environmental benefits: those are summary of total investment costs for suggested plant components, plant output in relation to energy demand, profitability, sensitivity analysis regarding different interest and discount rates, calculation of total emissions and Environmental comparison to landfilling.

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CHAPTER THREE

METHODOLOGY

3.1. Material of the study

Adama, better known as Nazret or Nazerth, is a city in central Ethiopia and the previous capital of the Oromia Region. It is located at $8^0$33'N $39^0$16'E/8.55^{0}N 39.27^{0}E at an elevation of 1712 meters, 99 kilometers southeast of Addis Ababa as shown in Figure 3.1.

Figure3. 1 Adama city the capital city of Oromia

According to the 2007 census, this city has total population of 220,212, an increase of 72.25% over the population recorded in the 1944 census. A total of 60,174 households were counted in this city which results in an average of 3.66 persons to a household.

In line with the average per capita of the country's garbage production, the city generates an estimated 110,106 kilograms of garbage per day. Currently the municipality is capable of collecting 43% of the waste generated in the city, with the remaining 57% indiscriminately disposed of in drainage lines, open spaces, or street sides or burn (AAU, 2007).

Adama is located near Addis Ababa, where high concentrations of large and small scale manufacturing activities are found and produce significant amounts of industrial waste. The final disposal site is found 8 kilometers out of the city (on the road to Addis Ababa). The total area coverage is 14,000m^2 with 1-meter depth, which is about 4,200m^3 of total volume Adama city administration,(2004).

The municipality has assigned two trucks with a capacity of 7m^3 and 5m^3(manual loading) to collect street and household waste. The trucks are intended to collect waste and transport it to the disposal site four times per day, but due to technical and other constraints the trucks are unable to meet this threshold.

There are 24 garbage collection containers of capacity 7 and 8 m^3distributed in different areas of the city. Waste collection from companies and households to pre-collection containers is done in part by 8 legally registered micro and small enterprises (MSE). These MSE have different material capacity and manpower. Most of them use wheelbarrows (hand pushed carts), and some have horse-drawn carts.

3.2. Thesis organization

The work during this master thesis has been divided into three different work periods: preparation work, field study and final work.

During the preparation stage an extensive literature study was conducted, to gain knowledge about waste-to-energy techniques and waste management. This literature study was the base for the background section and the theoretical framework in this project. During this stage of the project a model was made to simulate the energy output of a waste-to-energy plant. This model was based on thermo-dynamical formulas and incineration theory from Alvarez, (2006).

The field study was conducted in Adama, Ethiopia done by Mengist, (2014). The majority of the work was performed in the sub district of Adama in kebeles of 5,8,9,and 12. During these field trips data about the waste and waste management in the region was collected. If no documented information was available the data was collected through interviews. The waste data retrieved was used as input in the waste-to-energy plant model.

3.3. Methods of data collection

In this feasibility study data used primary and secondary data collection method; the data behavior is descriptive in nature. In view of this, in order to understand and deal with the complex phenomena of SWM in the city, the research design of this study involved a hybrid approach Viz, qualitative and quantitative methodologies. Data were gathered through primary data supplemented by field observation and self-administered questionnaire. The analysis of the data employed SPSS software. In addition, secondary data were gathered from documents Mengist, (2014).

A total of 26 persons were interviewed from different stakeholders based on their experience and involvement in the SWM activities including households, city administration, Environmental protection Bureau, Health Bureau and Micro and small Enterprises (MSE_S).open-ended questions were used during the interviews to understand respondents' views about the extent of waste management activities such as waste composition staffing, infrastructure, and fee Mengist, (2014).

The findings from the interviews and literature review provided a workable framework to develop a survey questionnaire. Self-administered questionnaire was used to describe the aspects, practices and challenges of SWM. The composition of respondents and the response rate by target kebeles or county is illustrated in Table 3.1. For the purpose of administering the questionnaire, 4 kebeles which are most prone to SW problems were purposively selected for having large number of industries, business places and population size (Mengist, 2014).

Table3. 1 Sample Composition of the targeted kebeles

Kebeles		Households		Organization		
	Sample size	No. of response	Sample response	Sample size	No. of response	sample proportion of response
5	45	34	15.96	31	21	22.83
8	50	45	21.13	32	25	27.17
9	94	83	38.97	42	32	34.78
12	55	51	23.94	26	14	15.22
Total	244	244	213	131	92	100

The sample size was taken to be 138. Considering compensation for non-responses, for instance, the sample size for households is assumed to be 244. Accordingly, a total of 375(244+131) questionnaires were distributed to the target categories (households and other organizations) and 305 questionnaires (213+92) were filled and returned (81.33% response rate). Prior to data gathering the questionnaire was pre-tested for ease of understanding and content validity Mengist, (2014).

3.4. Characterization of waste

Respondents were requested to express their views about the characterization of waste composition and the amount generated. The result is illustrated in Figure 3.3. As shown in figure 6, 42% of the household and 16% of the respondents from other organizations reported that food and food related wastes constituted larger portion of the SW generated followed by SW from plastics.

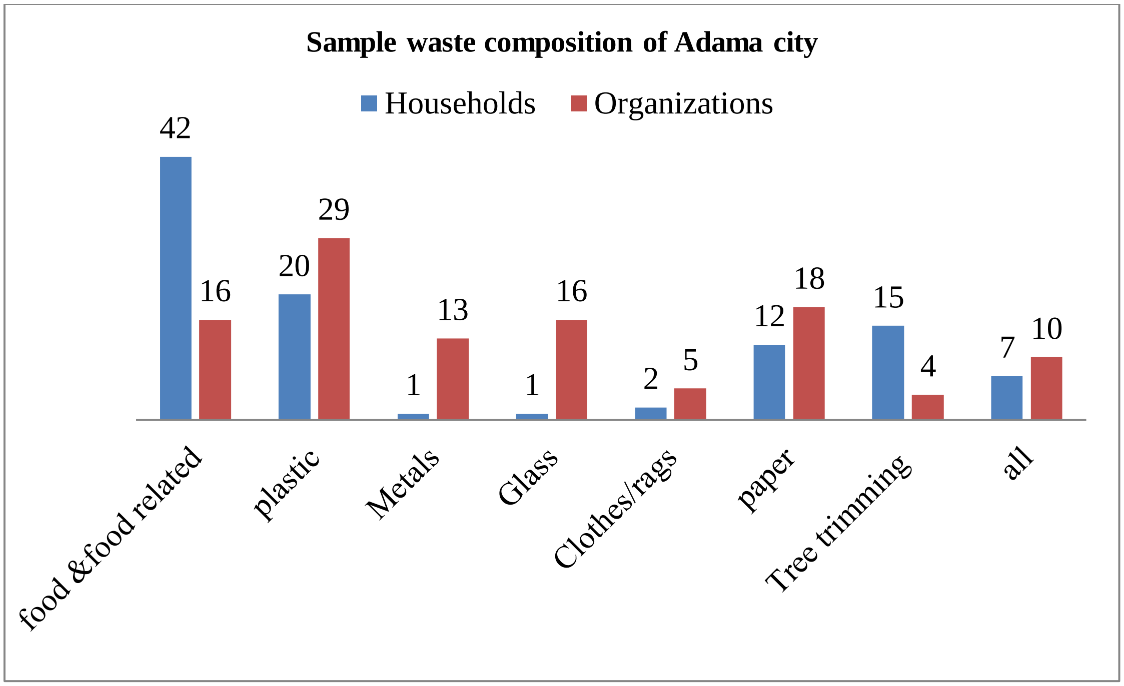

Figure3. 2 Waste Composition (Mengist, 2014)

The specifications for this project have been chosen to reduce regional landfilling of by 45,000.17 tons/year using waste incineration technology. Stating that largest stream of municipal solid waste (MSW) in developing countries is from food wastes. Regarding the amount of waste generated as shown in Figure 3.3, majority of the households (75%) and (30%) from organizations generated less than 25kg/week while 21% of households and 40% others generated 25-50 kg/week.

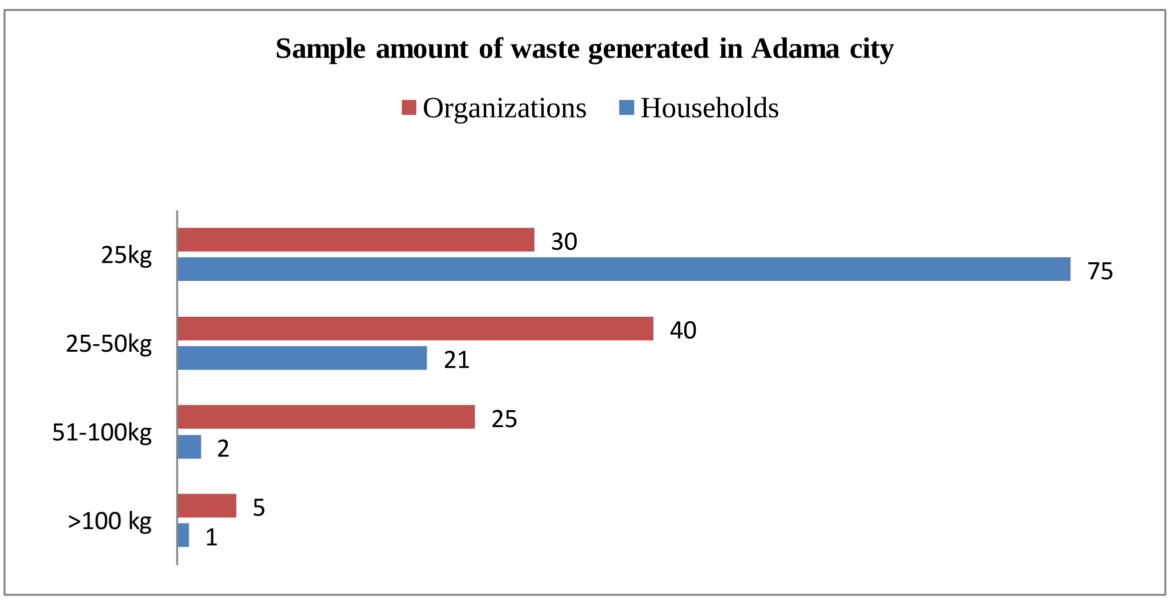

Figure3. 3 Waste Composition (Mengist, 2014)

Regarding the methods respondents used to dispose the waste at their source, 44% of the respondents stated that they damped food and food related waste, glass/ceramics, vegetable, and fruit in containers while they mostly burned tree trimmings, papers and plastics. Another 17% stated that they recycled clothes/rags wastes. It was also found that the use of waste as fertilizer and the concept of disposing waste from the source were minimal.

3.5 Waste storage and sorting

When requested about the use temporary storage for solid waste (SW) and sorting at the source, almost all respondents stated that they have temporary storage. 66% of respondents from organizations implied that they stored SW separately while 58% of households stored indiscriminately. The more information is shown in Table 3.2.

Table 3.2 Waste storage and sorting

Items and Responses		Households (%)	Organizations (%)
Use of temporary storage	Yes	99	100
	No	1	0
store separately	Yes	42	66
	No	58	34

In terms of the type of temporary storage used according to the data shown (Fig.3.4), majority 85% of households and 50% of organizations used sacks.

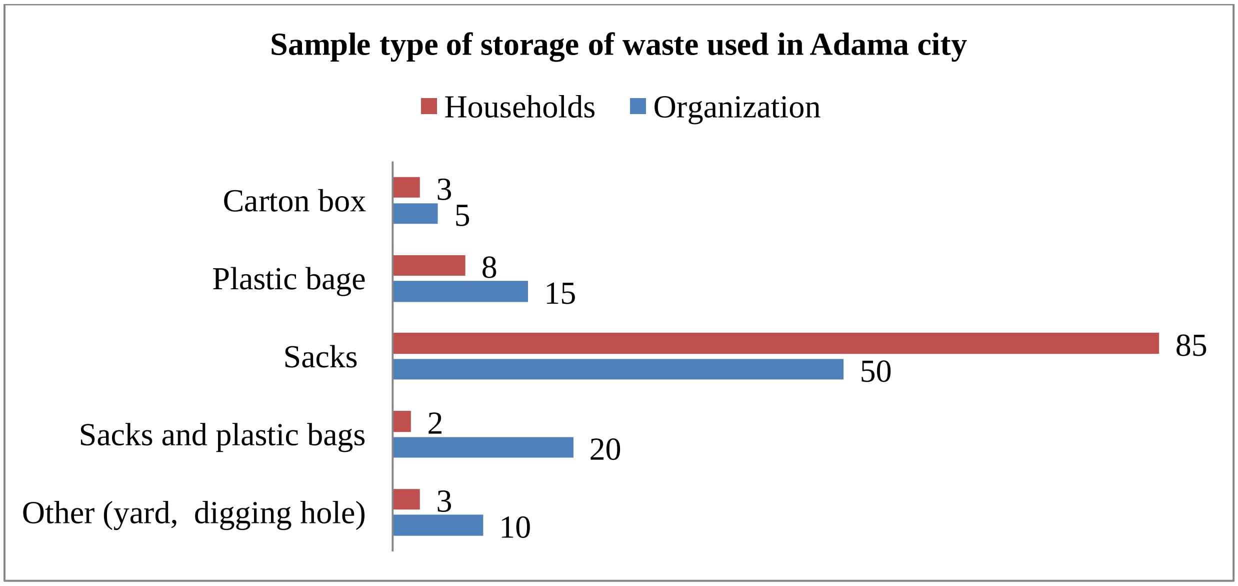

Figure3. 4 Types of storage used

Regarding the waste collection and disposal services, most of the respondents from the households (69%) as well as the respondents from organizations 60% stated that their waste was disposed by small micro enterprises (SMEs) while the city administration gave the service sometimes. Regarding the frequency of disposal services, most of the time households reported they got the service more than three times in month and organizations only once in a month Mengist, (2014).

3.6 Tools used for modeling the system

There are four tools for modeling system study of feasibility study of solar assisted waste to energy power plant for Adama city, those are CYCLEPAD, PYTHON, MECH IN EXCEL, and EXCEL.

3.6.1 CYCLEPAD software

Professor Kenneth Forbus of the computer science and education department at Northwestern University has developed ideal intelligent computer software for thermodynamic students called CYCLEPAD. It is cognitive engineering software. It creates a virtual laboratory where students can efficiently learn the concepts of thermodynamics, and allows systems to be analyzed and designed in a simulated, interactive computer aided design environment. The software guides students through a design process and is able to provide explanations for results and to coach students in improving designs Chih, (2007).

3.6.2 CYCLEPAD open system devices

Since the majority of engineering devices may be modeled as operating under steady state, steady flow conditions; a major of CYCLEPAD is devoted to the analysis of systems with steady state, steady flow processes. The following devices in the open system inventory shop of CYCLEPAD are used to illustrate the usefulness of the general principles and to strengthen our understanding of the basic thermodynamic principles.

The devices in the open system inventory shop of CYCLEPAD are typical devices used in thermodynamics and energy industry. A short statement of each device’s purpose, known facts about work and heat transfer, and a common assumption if appropriate is made in the following sections.

3.6.3. The general assumption of first low of thermodynamic for open system device.

Application of the first law of thermodynamics shown in the following expression, starting from the conservation of mass to the open system becomes.

$$m_2-m_1=m_i-m_e \quad (3.1)$$

$$m_2-m_1=(\rho_i V_i A_i-\rho_e V_e A_e)\Delta t \quad (3.2)$$

$$\int Time\ from\ t1\ to\ t2\ dm = \int inlet\ section\ dmi - \int exit\ section\ dme \quad (3.3)$$

$$\int Time\ from\ t1\ to\ t2\ dm = \int inlet\ sections\ \rho iVidAi - \int exitsections\ \rho eVedAe \quad 3.4)$$

Equation (3.2) is the algebraic from of Equation (3.1); Equation (3.3) and Equation (3.4) are the integral forms of Equation (3.1), respectively.

$dm=dm_i-dm_e$ (3.5)

Equation (3.5) is the differential forms of Equation (3.1)

$\Delta m/\Delta t=m_i/\Delta t-m_e/\Delta t$ (3.6)

Equation (3.6) is the finite time rate form of Equation (3.1), where $\Delta m=m_2-m_1$, and $\Delta t=t_2-t_1$, respectively

$dm/dt = mdot_i-mdot_e$ (3.7)

Equation (3.7) is the differential time rate form of Equation (3.1), the time rate of the law of conservation of mass for an open system.

Many engineering processes that operate under a steady condition for long period of time are called steady-flow processes. A steady system is one whose quantities such as mass and properties within the system do not change with respect to time. A steady-flow process is a process whose flow quantities at inlet and exit boundary sections do not change with respect to time. Equation (3.9), the low of conservation of mass for an open system becomes.

$m2-m1=0$ (3.8)

$mdot_i=mdot_e$ (3.9)

$\rho_i V_i A_i=\rho_e V_e A_e$ (3.10)

The general first law of thermodynamics

$E_2-E_1=Q_{12}-W_{12}+E_i-E_e$ (3.11)

$E_2-E_1=Q_{12}-W_{12}+E_{pi}+E_{ki}+U_i+PV_i-(E_{pe}+E_{ke}+U_e+PV_e)$ (3.12)

Where E is the total energy

The total energy (E) is made of potential energy (E_p), kinetic energy (E_k), internal energy (U) and flow energy (PV), i.e $E=E_p+E_k+U+PV$. Notice that flow energy (or called flow work in some textbooks) is the energy required to push a volume in (or out) by pressure across the boundary surface of the open system. Thus energy contained within the open system does not have flow energy.

Also notice that the boundary work is zero in the case of the open system, which is considered to be a volume of fixed identity, i.e., dv=o therefore $W_{boundary}=\int pdv = 0$. Hence, the total work

(w) in Equation (3.11) is made of shaft work (W_{shaft}) only if the other modes of work are not presented.

$W=W_{boundary}+W_{shaft}=W_{shaft}$ (3.13)

Various special forms of the first low of thermodynamics for an open system can be written. For example, the amount of energy change($\int dE$) from time t_1 to time t_2 can be expressed as.

$\int dE = \int \partial Q - \int \partial W + \int inlete\ section\ dEi - \int exit\ section - dEe$ (3.14)

Equation (3.14) is the integral from of Equation (3.11)

$dE=\partial Q-\partial W+dEi-dEe$ (3.15)

Equation (3.15) is the differential from of Equation(3.11)

$\Delta E/\Delta t=Q_{12}/\Delta t-W_{12}/\Delta t+\Delta E_i/\Delta t-\Delta E_e/\Delta t$ (3.16)

Equation (3.16) is the finite time rate form of Equation (3.11), where $\Delta E=E_2-E_1$, and $\Delta t=t_2-t_1$ respectively.

$dE/dt=Qdot-Wdot+Edot_i-Edot_e$ (3.17)

Equation (3.17) is the differential time rate from of Equation (3.11).

For steady flow, the change in mass and energy within the open system are both zero.

$E_2-E_1=0$ and $m_2-m_1=0$ (3.18)

Thus the various forms of the First law of thermodynamics of an open system [Equations (3.11),(3.12),(3.14),(3.15),(3.16) and (3.17)] are reduced to.

$0=Q_{12}-W_{12}+E_i-E_e$ (3.19)

$0\ x \int = \int \partial Q - \int \partial W + \int inlete\ section\ dEi - \int exit\ section - dEe$ (3.20)

$0= \partial Q-\partial W+dE_i-dE_e$ (3.21)

$0= Q_{12}/\Delta t-W_{12}/\Delta t+\Delta E_i/\Delta t-\Delta E_e/\Delta t$ (3.22)

$0= Qdot-Wdot+Edot_i-Edot_e$ (3.23)

The specific form of the First law of thermodynamics of an open system [Equations (3.23)] becomes

$0= q_{12} - w_{12}+e_i-e_e$ (3.24)

3.6.4. Heater (including boiler, steam generator, super heater, combustion chamber, burner, evaporator. reheater, preheater and open feed water heater)

A heater is a simple single steam fluid flow through a device where heat is transferred to the fluid from the surroundings. The fluid is heated and may or may not change phases. For example, a boiler is a vapor generator in which a liquid is converted into a vapor by the addition of heat; a steam generator is the same as boiler that heats liquid pure substance to vapor or superheated vapor phase; a super heater brings a substance temperature over saturated temperature; an evaporator brings a substance to vapor state; a reheater is a heater used between turbine stages. The heating process tends to occur at constant pressure, since a fluid flowing through the devices usually undergoes only a small pressure drop due to fluid friction at the walls. There is no means for doing any shaft or electric work, and changes in kinetic and potential energies are commonly negligible small.

Application of the first law of thermodynamics to a heater gives

$W = 0$, $E_k = 0$, and $E_p = 0$ (3.25)

$Q = m(h_e - h_i)$ (3.26)

Heaters in various applications are called boiler, superheater, combustion chamber, evaporator, reheater, preheater, open feed water heater, etc. A boiler is steam generator that receives heat and converts liquid water vapor at constant pressure. A superheater raises the temperature of saturated vapor at constant pressure. A combustion chamber is a device into which fuel and air are admitted, the fuel is burned, heat is released, and exhaust gases are discharged. A reheater receives heat and raises the temperature of liquid or gas at constant pressure. An open feed water heater receives heat and raises the temperature of liquid water at constant pressure, Figure 3.5 shows how look like boiler.

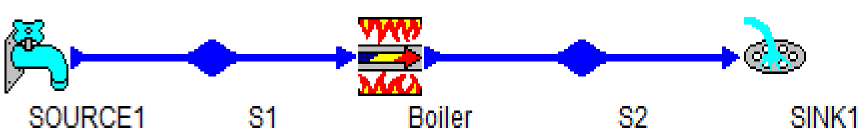

Figure3.5 Water boiler

3.6.5. Cooler (including condenser, intercooler, Precooler and aftercooler)

A cooler is a simple single stream fluid flow through a device where heat is removed from the fluid to the surroundings. For example, a condenser takes heat out to bring a pure substance from vapor state or saturated mixture state to liquid state; an intercooler is a cooler used between compressor stages. The fluid is cooled and may or may not change phases. The cooling process tends to occur at constant pressure, since a fluid flowing through the device usually undergoes only a small pressure drop due to fluid friction at the walls. There are no means for doing any shaft or electric work, and changes in kinetic and potential energies are commonly, negligibly small.

Application of the First law of thermodynamics to a flow steady system cooler gives.

$W = 0$, $E_k = 0$, and $E_p = 0$ (3.27)

$Q = m(he-hi)$ (3.28)

Coolers in various applications are called condenser, inter-cooler, etc. Heat is removed from a condenser and convert vapor or saturated mixture steam into liquid water at constant pressure, Figure 3.6 shows the process of condenser and the result also display.

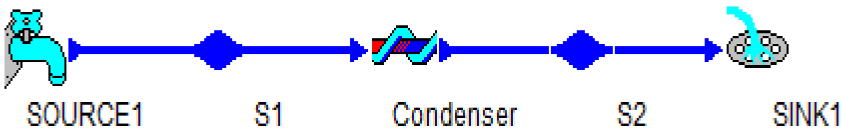

Figure3. 6 Condenser Cooler

3.6.6. Turbine

Turbines are high-speed rotating devices used to produce work. In a turbine, much of the energy content of a high-pressure, high-temperature working fluid passing through the turbine is expanded and mechanical shaft work is produced. For example, in a power plant, steam at high pressure and temperature is used to turn a series of turbine wheels. Working fluid in a turbine is expanded from a high pressure and high temperature inlet state to a low pressure exit state. The temperature of the working fluid also drops during the expansion process. A turbine is usually modeled as adiabatic.

Generally, changes between inlet and outlet kinetic and potential energies are very small in comparison with changes in enthalpy. Application of the First law of thermodynamics to steady flow turbine gives.

$Q = 0$, $E_k = 0$, and $E_p = 0$ (3.29)

$W = m(h_i-h_e)$ (3.30)

The adiabatic assumption is reasonable because the heat transfer surface area of the turbine is relatively small, and the length of time required for the working fluid to pass through the turbine is short. As a result, the ideal expansion process is considered to be reversible and adiabatic, or isentropic. Figure 3.7 the representation of turbine how modeled. Comparison between the actual and the ideal turbine performance is given by the turbine efficiency, η. Since an ideal turbine produces more isentropic work than the actual work by an actual adiabatic turbine efficiency, η, is defined as.

$\eta = W_{actual}/W_{isentropic}$ (3.31)

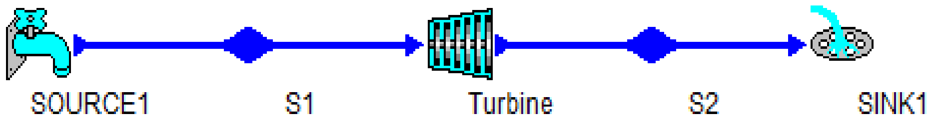

Figure3. 7 The representation of Turbine

3.6.7. Pump

The purpose of a pump is to compress a liquid from a law pressure inlet state to a high pressure exit state by utilizing mechanical work. Pump has the same function as compressor but handles liquid. Ideal adiabatic pump work is $\int vdp$. Therefore, pumping a liquid is more efficient than compressing a gas, because one can pump a great deal more liquid per unit volume, and liquids, being basically incompressible, do not again an appreciable amount of heat during the pumping process. A pump is usually modeled as adiabatic.

Generally, changes between inlet and outlet kinetic and potential energies are very small in comparison with changes in enthalpy. Application of the first law of thermodynamics to a steady flow system pump gives.

$Q = 0$, $E_k = 0$, and $E_P = 0$ (3.32)

$W = m(h_i - h_e)$ (3.33)

Since liquid is an incompressible substance and liquid temperature change across the pump is negligible. Equation (3.33) can be reduced to.

$W = mv(p_i - p_e)$ (3.34)

The adiabatic assumption is reasonable because the heat transfer surface area of the pump is relatively small, and the length of time required for the working fluid to pass through the pump is short. Therefore, the ideal pumping process is considered to be a reversible and adiabatic or isentropic one. Figure 3.8 the representation of pump in this feasibility study. Comparison between the actual and the ideal pump performance is given by the isentropic efficiency, η, since it requires more actual work to drive an actual pump than the ideal work to drive an isentropic pump, the pump efficiency, η, is defined as.

$\eta = W_{isentropic}/W_{actual}$ (3.35)

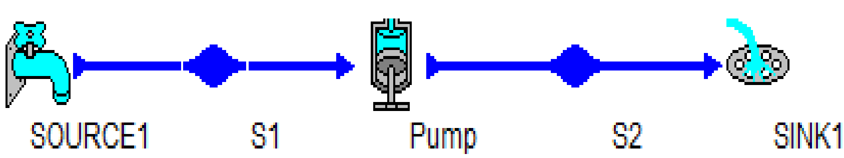

Figure3. 8 pump model representation

3.6.8. Mixing chamber

A mixing chamber is a device to mix two or more streams of fluids into one stream. The mixing chamber does not have to be a distinct chamber. An ordinary T-elbow is a shower, for example, serves as a mixing chamber for the cold- and hot-water steam. Mixing chambers are usually well insulated (Q=0) and do not involve electric or shaft work. Also, the kinetic and potential energies of the working fluid streams are usually negligible. A desuperheater addis liquid water to superheated vapor pure substance to make it saturated vapor. A desuperheater is usually considered to be an isobaric process.

Generally, changes between inlet and outlet kinetic and potential energies are very small in comparison with changes in enthalpy. , Figure 3.9 show the schematic representation of mixing chamber. Application of the mass balance equation and the first law of thermodynamics to a steady flow mixing chamber gives that the total mass rate flow in at the inlets is equal to the total mass rate flow out at the exit of the mixing chamber.

$$Q = 0, W = 0, E_K = 0, \text{ and } E_p = 0 \tag{3.36}$$

$$\sum(mdot)in = \sum(mdot)out \tag{3.37}$$

$$\sum[(mdot)in(hin)] = \sum[(mdot)out(hout)] \tag{3.38}$$

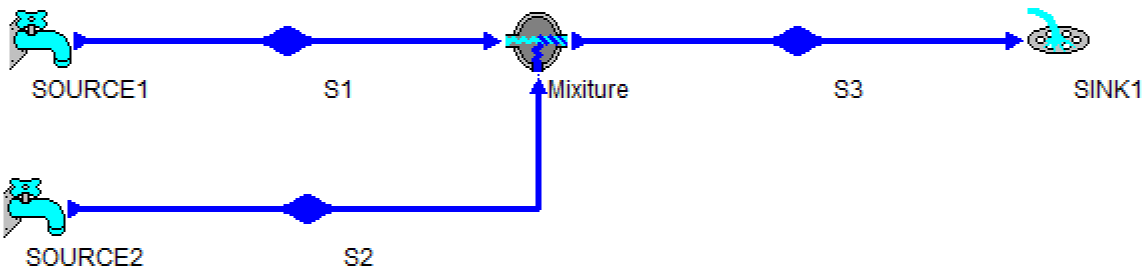

Figure3. 9 Mixing chamber

3.6.9. Splitter

A splitter is a device to split one stream fluid into two or more streams of fluids. The splitter does not have to be a distinct chamber. An ordinary Y-elbow in a shower, for example, serves as a splitter. Splitters are usually well insulated (Q=0) and do not involve shaft work. Also, the kinetic and potential energies of the working fluid streams are usually negligible.

Generally, changes between inlet and outlet kinetic and potential energies are very small in comparison with changes in enthalpy. Figure 3.10 show the model of splitter. Application of the mass balance equation and the first law of thermodynamics to a steady flow steady state splitter give the total mass rate flow in at the inlets equal to the total mass rate flow out at the exit of the splitter, and the total enthalpy rate flow in at the inlet equal to the total enthalpy rate flow out at the exits of the splitter mixing chamber.

Q = 0, EK = 0, W = 0, and Ep= 0 (3.39)

$$\sum(mdot)in = \sum(mdot)out \quad (3.40)$$

$$\sum[(mdot)in(hin)] = \sum(mdot)out(hout)] \quad (3.41)$$

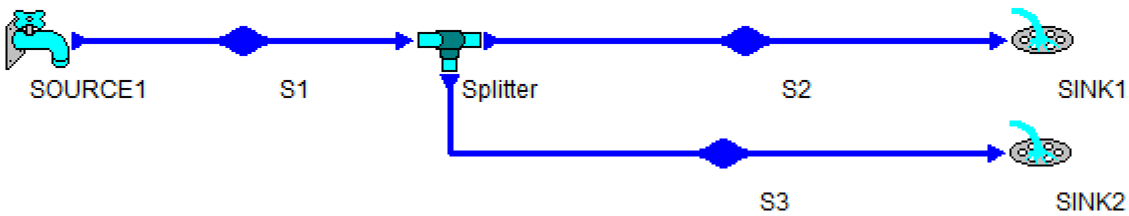

Figure3. 10 splitter

3.6.10. Heat Exchanger

A heat exchanger uses multi stream fluids (usually two streams) flowing through a device where heat is transferred from one stream fluid at a higher temperature to the other stream fluid at a lower temperature. The fluids are heated or cooled and may or may not change phases. The heat exchanging process tends to occur at constant pressure, since the fluids flowing through the device usually undergo only small pressure drops due to fluid friction at the walls. There are no means for doing any shaft work. Energies are exchanged from one stream fluid to another stream fluid inside the heat exchanger. There is no heat interaction with the surroundings. An economizer is a low-temperature and low-pressure heat exchanger. A regenerator is a heat exchanger used to recover energy.

Generally, changes between inlet and outlet kinetic and potential energies are very small in comparison with changes in enthalpy. Figure 3.11 show the heat exchanger. Application of the mass balance equation and the First law of thermodynamics to a steady flow steady state heat exchanger, the total mass rate flow in at inlets is equal to the total mass rate flow out at the exit of the mixing chamber, and the total enthalpy rate flow in at inlets is equal to the total enthalpy rate flow out at the exit of the mixing chamber.

Q = 0, W = 0, E_k = 0, and E_p = 0 (3.42)

$$\sum(mdot)in = \sum(mdot)out \quad (3.43)$$

$$\sum[(mdot)in(hin)] = \sum[(mdot)out(hout)] \quad (3.44)$$

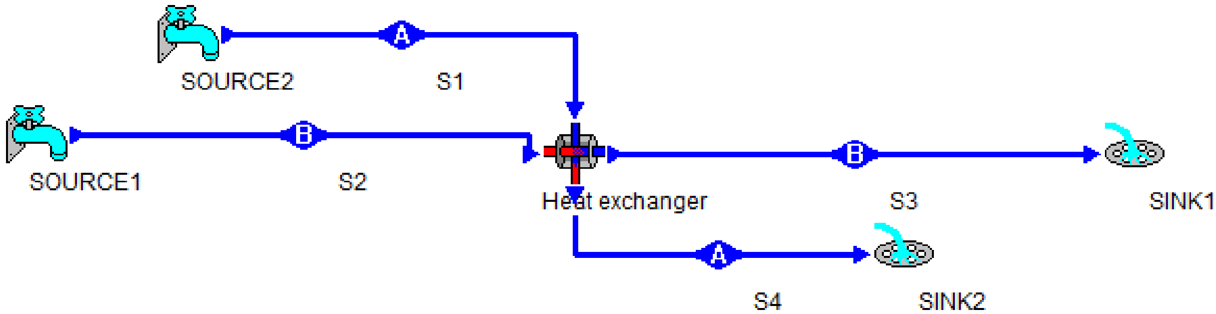

Figure3. 11 Heat Exchanger

3.6.11. Throttling valve

A throttle or a valve is called a throttling valve which is an inexpensive control device which, by an obstruction in its through-flow reduces the pressure of the working fluid. It is used to regulate the pressure of a fluid. It is also used to measure mass flow rates and quality of a mixture. It can also be utilized to reduce the power or speed of a heat engine. Throttling processes occur in obstructed flow passages such as valves, flow meters, capillary tubes, and other devices that reduce the pressure of the working fluid without any shaft work or heat interactions. There is neither work nor heat transfer interaction between the valve and its surroundings.

Application of the First law of thermodynamics (neglecting kinetic and potential energy changes) to a steady flow steady state throttling valve gives.

$$Q = 0, W = 0, EK = 0, \text{ and } Ep = 0 \quad (3.45)$$

$$h_e = h_i \quad (3.46)$$

Therefore, the process experienced by a fluid when it goes through a throttle valve, a porous plug, or a plate with a very small hole in it is called the throttling process. A throttling process is a constant enthalpy process. The inlet enthalpy of the working fluid of a throttling valve is equal to the exit enthalpy of the working fluid. Reducing the pressure of the working fluid in throttling manner involve considerable irreversibility Figure 3.12 show throttling valve.

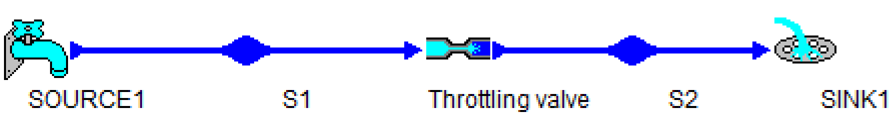

Figure3. 12 Throttling Valve

3.7. Exergy of a flow stream and flow exergy change of an open system.

A flowing fluid has an additional form of energy called flow energy. Flow energy, PV, is the energy required to push a volume V of a flowing stream substance through a surface section by a pressure p. Flow energy occurs only when there is mass flow stream into an open system or out from the open system. Similarly, assuming kinetic energy and potential energy are negligible, properties are uniform at a section of a flow stream, and the useful reversible work of the flow stream is.

$$W_{useful\ reversible} = (U + p_oV - T_oS) - (U_o + pV_o - T_oS_o) + (p - p_o)V \quad (3.47)$$

Where the term (p-po)V is the flow work and the work done against the environment. Under steady flow conditions, Equation (3.47) can be rearranged as

$$W_{useful\ reversible} = (H - H_o) - T_o(S - S_o) \quad (3.48)$$

The flow exergy of the fluid, **Ψ**, can be defined as

$$\Psi = (E - Eo) - To\ (S - So) = (H - Ho) - To\ (S - So) \quad (3.49)$$

The specific flow exergy change (ΔΨ) of a fluid stream for an open system without work and heat transfer during a process i-e is the difference between the exit and inlet section specific exergies of the system.

$$\Delta\Psi = \Psi_e - \Psi_i = (h_e - To\ S_e) - (h_i - T_oS_i) \quad (3.50)$$

The rate of exergy change of an open system can be written as

$$\Delta\Psi doti = mdote\ (he - ToSe) - mdoti(hi - ToSi) \quad (3.51)$$

To generalize to more than one inlet and more than one exit, the flow exergy change and rate of flow exergy change of an open system can be written as.

$$\Delta\Psi = \sum(H - ToS)e - \sum(H - ToS)i \quad (3.52)$$

$$\Delta\Psi doti = \sum mdote(he - ToSe) - \sum mdoti(hi - ToSi) \quad (3.53)$$

3.8. The decrease of exergy principle

Let us consider a thermodynamic isolated system with its surroundings at temperature T_o. The isolated system has neither mass nor energy interaction with its surroundings. That is, mi = 0, Ei = 0, Ee = 0, Q = 0, and W = 0, where mi is the mass flow into the system, me is the mass flow out from the system, Ei is the energy flow with mass into the system, me is the energy flow with mass out from the system, Q is the microscopic energy flow without mass into the system, and W is the macroscopic energy flow without mass into the system.

The mass balance of the system is the conservation of mass principle, which indicates that mass cannot be created nor destroyed. The mass balance of the isolated system is.

$$m_2 - m_1 = m_i - m_e = 0 \qquad (3.54)$$

Where m_1 is the initial amount mass of the system and m_2 is the final amount mass of the system. The First law of thermodynamics is the conservation of energy principle, which indicates that energy cannot be created nor destroyed. The energy balance of the isolated system is.

$$E_2 - E_1 = Q - W + E_i - E_e = 0 \qquad (3.55)$$

Where E1 is the initial amount energy of the system and E2 is the final amount energy of the system. According to the second law of thermodynamics, the entropy generated by the system due to internal irreversibility is.

$$S_{gen} = S_2 - S_1 > 0 \qquad (3.56)$$

Where S_1 is the initial amount entropy of the system and S_2 is the final amount entropy of the system.

Multiplying Equation (3.56) by the surroundings at temperature T_o, and subtracting it from Equation (3.55) yields.

$$-T_o S_{gen} = E_2 - E_1 - T_o(S_2 - S_1) < 0 \qquad (3.57)$$

Rearranging Equation (3.57) gives

$$-T_o S_{gen} = \Phi 2 - \Phi 1 < 0 \qquad (3.58)$$

Since the absolute temperature is always positive, we conclude that the exergy of an isolated system during a process always decreases due to irreversibility. In the limiting case of a reversible process, the exergy of the isolated system remains the same.

$$\Phi 2 - \Phi 1 < 0 \text{ for irreversible process} \qquad (3.59)$$

$$\Phi 2 - \Phi 1 = 0 \text{ for reversible process} \qquad (3.60)$$

$$(\Delta\Phi)_{\text{isolated system}} < 0 \text{ for irreversible process} \qquad (3.61)$$

$$(\Delta\Phi)_{\text{isolated system}} = 0 \text{ for reversible process} \qquad (3.62)$$

Equation (3.61) and Equation (3.62) are known as the decrease of exergy principle. For an isolated system, the decrease in exergy equals exergy destroyed.

The exergy destroyed ($\Phi_{destroyed}$) of a system is proportional to the entropy generated of the system due to irreversibility such as friction, free expansion, chemical reactions, mixing, etc.

$\Phi_{destroyed} = T_o S_{gen}$ (3.63)

The exergy destroyed ($\Phi_{destroyed}$) of a system is a non-negative quantity. The exergy destroyed is positive for an irreversible process and zero for a reversible process. The exergy destroyed is also called the irreversibility. Equation (3.63) is applied to both isolated system and non-isolated system.

Note that the exergy change of a system can be positive or negative just like that the entropy change of a system can be positive or negative during a process. When heat is removed from a non-isolated system to its surroundings, entropy of the system is decreased and the exergy of the system is increased.

3.9. Exergy cycle efficiency

Let us define an exergy cycle efficiency, $\eta_{ex.}$ The exergy cycle efficiency can be expressed as the ratio of desirable exergy transfer output and the required input energy of the cycle, i.e.

η_{ex} = (desirable exergy transfer output)/(required input energy) (3.64)

The exergy cycle efficiency is conceptually different from the cycle efficiency. The exergy cycle efficiency can be used to see whether a realistic cycle is well design or not.

3.10. Basic rankine vapor cycle

The working fluid for vapor cycles is alternately condensed and vaporized. When a working fluid remains in the saturation region at constant pressure, its temperature is also constant. Thus the condensation or the evaporation of a fluid in a heat exchanger is a process that closely approximates the isothermal heat transfer processes of the Carnot cycle. Owing to this fact, vapor cycles are closely approximate the behavior of the Carnot cycle. Thus, in general, they tend to perform efficiently.

The Rankine cycle is a modified Carnot cycle to overcome the difficulties with the Carnot cycle when the working fluid is a vapor. In the Rankine cycle, the heating and cooling processes occur at constant pressure. Figure 3.13 shows the devices used in a basic Rankine cycle, and Figure 3.11 is the T-s diagram of the basic Rankine cycle.

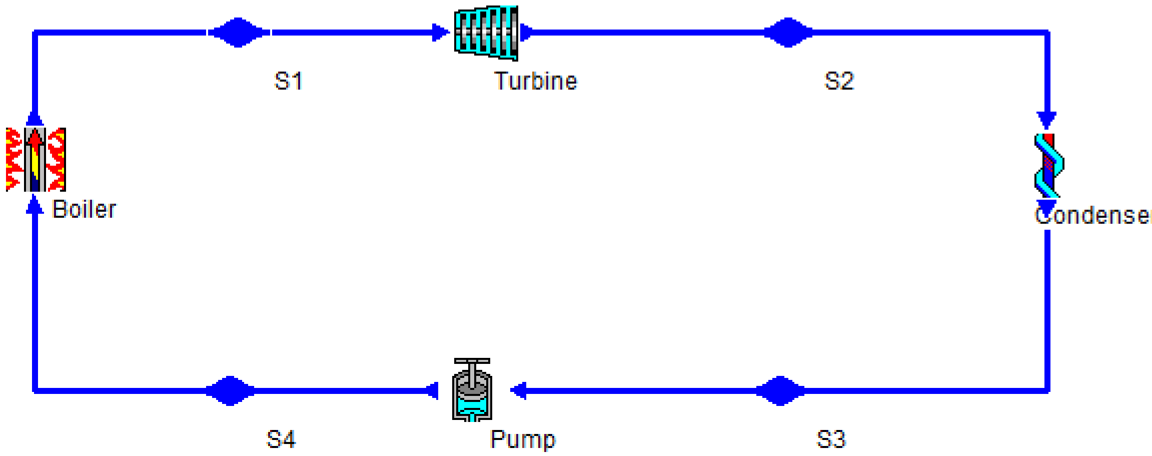

Figure3. 13 Basic Rankine cycle

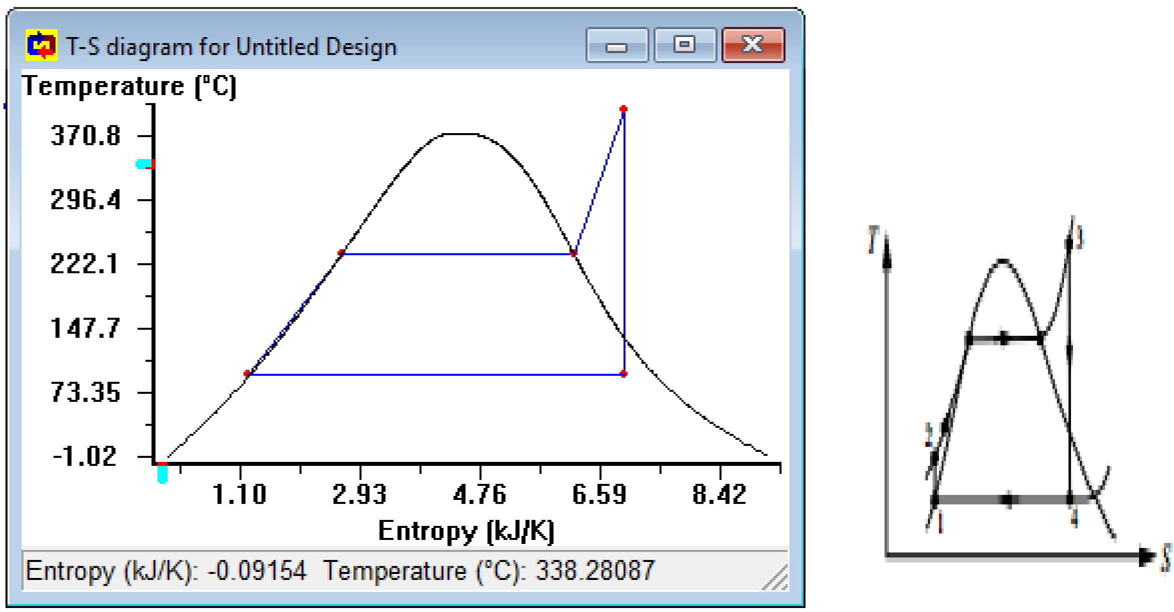

Figure3. 14 Basic Rankine cycle T-S digram

The basic Rankine cycle is composed of the following four processes.

- 1-2 isentropic compression
- 2-3 isobaric heat addition
- 3-4 isentropic expansion
- 4-1 isobaric heat removing

Applying the First law and Second law of thermodynamics of the open system to each of the four processes of the Rankine cycle yields:

$Q_{12} = 0$ (3.65)

$W_{12} = m(h_1-h_2) = mv_1(p_1-p_2)$ (3.66)

$W_{23} = 0$ (3.67)

$Q_{23} - 0 = m(h_3-h_2)$ (3.68)

$Q_{34} = 0$ (3.69)

$W_{34} = m(h_3-h_4)$ (3.70)

$W_{41} = 0$ (3.71)

$Q_{41} - 0 = m(h_1-h_4)$ (3.72)

The network (W_{net}), which is also equal to net heat (Q_{net}) , is

$W_{net} = Q_{net} = Q_{23} + Q_{41}$ (3.73)

The thermal efficiency of the cycle is

$\eta = W_{net}/Q_{23} = Q_{net}/Q_{23} = 1 - Q_{41}/Q_{23} = 1 - (h_4-h_1)/(h_3-h_2)$ (3.74)

3. 11.Selection of incineration grate

In this feasibility study the choice of incineration technology is the moving grate method. It has ability to handle different waste compositions and the fact that it doesn't require any pretreatment of the waste. A rule of thumb for moving grate is that a single grate has a maximum feed capacity of 40 tone/h. With this in mind also for production safety reasons, there will be two separate grate and boiler lines and for economical reasons they will have the same thermal capacity of output.

For assurance production temperature according to environmental regulations and to reduce the costs of operation, one should choose the solution that requires as little fuel, electricity and chemicals as possible. Auxiliary burners require oil or gas for support incineration, chemicals are used for the flue gas treatment and electricity is used for pumps and running mechanical components etc.

3.12. Selection parameter of Steam cycle components

An ideal steam cycle model has been constructed in CYCLEPAD, to help with the choice of components and technical specifications for them. The steam boilers, turbines, generator, cooling tower, district heating heat exchanger, condensate tank and feed water tanks have all been selected according to waste and DH conditions. Among them have predetermined values and some have dynamic values adapting to the other components.

3.13. Steam Boiler selection [SB]

Appropriate thermal capacity of the boilers has been determined from the feed flow and calorific value of the waste. To prepare for a probable future increase of waste amount and energy density, as unpredicted thermal spikes, a capacity margin is added to the theoretical value. This results in a proposed thermal capacity of 70MW, divided into two 35MW lines (Anderz Wahlstrom. VonRoll).

3.14. Selection of Turbines T[HP] and T[LP] & Generator [G]

The theoretical model has two back pressure turbine steps with an intermediary superheating step between them. Larger power plants with energy dense fuels usually have more steps, but they also come with higher investment costs that do not necessarily pay back in smaller plants.

Monthly average electrical output of the proposed plant will be around 16MW. The selection generator type is designed to operate efficiently at these conditions. The proposed solution is two siemens SST-300 systems.

3.15. Cooling Tower [CT]

During summer season the maximum thermal power output exceeds the DH demand. The plant primary goal is to treat all the incoming waste, this becomes a problem without another source of cooling, in this case the maximum cooling demand will be 45MW.

Given the conditions of the proposed location, a GEA dry system cooling tower, Air cooling condenser (ACC), will be proposed. These can be placed next to the power plant or as re-coolers in the district heating grid.

3.16. Flue gas treatment and particle separation

Selection of flue gas treatment system depends on the environmental regulations system. The Water supply at the suggested location and the potential for a wastewater treating system Adama for the case the system is not feasible according to the information collected. The proposed solution is a semi dry treatment system with hydrated lime as reluctant. A suggested type is the Alstom NID-system. This system demands a particle filter, in this case a bag filter with activated carbon.

3.16.1. Selection Equipment of Nitrogen reduction SNCR DeNO$_x$

Out of the two of DeNO$_x$ technology the SNCR is chosen for its simplicity and low investment cost. The system will use ammonia as reductant and the aforementioned particle separation is suitable for this technology.

3.17. Location selection

At this current stage no location for the Waste to Energy (WtE) plant is decided. The good suggestion that the plant should be located with the needs for infrastructure, waste supply and energy demand taken into account, by locating the plant along the Awash River, close to Adama the plant will have access to good logistical infrastructure, by trucks and boats, and close access to the waste supply. The river will also be used to cool excess heat.

3.18. Flue gas chimney height

According to the location and its population density, along with flue gas flow and climate conditions set the requirements for the chimney height of the plant.

In this feasibility study (WTE), the chimney height estimation is done based on stock height calculation document provided by the Swedish Environmental Protection Agency.

The input data in these calculations are flue gas flows, temperatures and geographical data obtained for the location from Google Earth.

$$H_o = H_{ref} + \Delta H_{sd} + \Delta H_{tb} + \Delta H_{bd} \text{ [m]} \tag{3.75}$$

Ho= building height [m]

Href= Reference Height of the chimney [m]

ΔHsd= Height additions due to draft in the lee of the chimney [m]

ΔHtb=Height additions due to terrain and buildings [m]

ΔHbd=Height additions due to draft at adjacent buildings [m]

CHAPTER FOUR

SOLID WASTE ANALYSIS

4.1. Waste Analysis Assessment

Knowing of the calorific values is essential in the selection of the appropriate waste-to-energy technology configuration and the estimation of energy output. Determining upper calorific value represents the total energy content necessary to evaporate the moisture content. In practice, this alue, however, is important because this is the energy content, which can be utilized for the production of thermal and electrical power.

The important component to consider in conducting any study for thermal utilization processes is moisture content. The plant will be equipped with a dryer that will reduce the moisture content before passing materials to a gasification center. The moisture content in the landfill site at any given time depends on the season and new garbage is estimated at around 47% moisture content.

As we know moisture has always a negative effect for thermal utilization. In order to guarantee an independent combustion (without auxiliary fuel) of mixed and moist MSW, the lower heating value should be above 7,000 kJ/kg Cambridge, (2017).

The determination of the energy value of waste is also possible through calculation of the energy potential of the different waste components. The formula for determining the calorific vlue of waste components is as follows:

$$CVraw = \left((1-w)x(CVupper-(2441x9)xH)\right)-2441xw) \tag{4.1}$$

Where

CV=Calorific value ("raw" is real" as delivered" value, "upper" is value for dried material) in KJ/Kg

W= percentage of moisture content (by weight)

H= percentage of hydrogen content (from literature values)

* Vaporization enthalpy of water (2441 kJ/Kg at 25^0c)

Calculating the calorific value of a waste stream the following steps were carried out;

- ✓ Sample is sorted and analyzed into fractions;
- ✓ CV_{upper} is applied from known data (literature);
- ✓ CV_{upper} is analyzed for unknown fractions;
- ✓ Percentage of Hydrogen is applied from known data (literature);
- ✓ Moisture of fractions is determined; and
- ✓ Calculate values for CV raw

According to the study of literature the collected waste in Adama on 2007 was 40,200tons, in the future this value increase to 50,000 tons/ year. The essential component to consider is the bulky waste fraction with a calorific value similar to or higher than MSW (8,000-11,000 MJ/ton).

4.2. Energy value determined from municipal solid waste (MSW) and Waste similar to MSW

These calculations are depending on the assumption that 50,000 tons of MSW are utilized in a thermal treatment facility. The calculation of the energy potential by combustion of these 50,000 tons of MSW is shown in the following calculation.

Calculation of the theoretical energy potential is based on the amount of 45,000 tons of MSW including waste similar to that generated from the commercial and industrial sectors and with an average calorific value of 9,500 mJ/t[10]; this calculation is based on the feasibility study of Rappi (koshe) power plant with assumption of similarity of MSW.

$$Mwaste \frac{tone}{time} x\ 9500 \frac{MJ}{1} \quad (4.2)$$

4.3. Analysis by using Rankine cycle

This analysis start from knowing the chemical composition of the waste material, I assumed solid waste material similar to Moldova country, which is developing country like us so I decide in order to calculate the solid waste material similar to Ethiopia.

4.3.2. Chemical Combustion

The heat generation in the incineration process is determined by a number of important reactions. Using data on waste composition and average chemical elements in waste components, the fractions of carbon, hydrogen and water can be calculated. Knowing the flow of fed in waste, and the fractions of the chemical compounds, allows for calculations of the heat generation in the combustion process.

Firstly, a certain amount of water in the fuel needs to evaporate before the fuel can combust. In order for the water in the fuel to evaporate it first needs to be heated to 100^0c. The energy needed to heat water from 20-100^0c is 334kJ/kg and evaporation requires 2257kJ/kg.

Secondly, the amount of molecular carbon and hydrogen in the fuel are the main contributors to the heat generation. The majority of the energy released while incinerating waste comes from two important chemical reactions:

$$C + O_2 \rightleftharpoons CO_2 + 33{,}913 (kJ/kg) \text{ Carbon Combusted} \quad (4.3)$$

$$2H_2 + O_2 \rightleftharpoons H_2O + 142{,}770 (kJ/kg) \text{ Hydrogen Combusted} \quad (4.4)$$

The molecular carbon and hydrogen react with the oxygen in the combustion air releasing their molecular binding energy into the flue gas.

Thirdly, since a waste combustion process requires a lot of air, there will be a surplus of nitrogen and oxygen that do not react in the combustion process but are heated to the same temperature as the flue gas.

$$C_p[N_2] = 1.04 kJ/(kg*k) \quad (4.5)$$

$$C_p[O_2]= 0.919 kJ/(kg*k \quad (4.6)$$

Finally, some heat is lost from the incombustible materials that leave the grate. In the combustion model, an average heat capacity is calculated for the inert components in the incineration process. The residue temperature is estimated to 100^{0}c when it leaves the grate, and this heat is considered as a loss.

4.4. Flue Gas Composition

gh This describes the highest theoretical temperature reached in an adiabatic combustion process, for a specific fuel source.

$$Tg = \frac{Hi+Iv*Cpl*t1}{gv*Cpg} \quad (4.7)$$

Tg=Theoretical flue gas temperature Hi=Calorific value of fuel Iv= Airflow (real)

Cpl=Specific heat capacity(Air) t1=Air temperature gv= flue gas flow(real)

Cpg=Specific heat capacity (flue gas)

The temperature distribution in a furnace can be distributed an evenly. The highest temperature in the furnace, close to the grate, will be close to the calculated theoretical one. The dimensions of the furnace and boiler, along with the grate air supply and auxiliary burners, will determine what temperature the flue gas will have at the steam heat exchange.

When designing the heat exchange system between furnace and boiler the goal is to maximize the boiler efficiency, while still operating at sustainable temperatures. The two most important limitations are set by the furnace heat resistance, which sets the highest temperature, and flue gas treatment requirements, which sets the lowest temperature. Usually, the flue gas needs to be treated in the temperature range between 155-130^{0}C. After this, a portion of the remaining flue gas energy content is used for pre-heating combustion air. At between 50-70^{0}C the rest of the energy is released through the chimney.

The main flue gas components in a WTE combustion process needed for heat transfer and emission calculations are: O_2, CO_2,H_2O, SO_2 and N_2. The amounts generated depend on the elemental composition of the waste and the amount of air supplied to the incineration process Alvarez (2006).

4.5. Model in CYCLEPAD and MECH IN EXCEL

To be certain that the best characteristics and configuration of the components in the steam cycle will be chosen, a calculation model was made in the program CYCLEPAD and Excel. The model varies the characteristics and configurations and determines which version is the most profitable in regard to sales of electricity and district heating. The annual production is divided into 12 months with different operating conditions. The two main physical relations that are used in the optimization program are mass balance and energy balance. The sum of energy flow into one node is equal to the sum of energy flow out of it, and the same applies to the mass flow. The system is approximated as an ideal system where no energy is lost. The optimization program is based on a schematic picture of the steam cycle that is showed in Figure 4.1 and explained in Table 4.1.

Regenerative Rankine cycle, the thermal efficiency of the Rankine cycle can be increased by the use of regenerative heat exchange as shown in Figure 4.1. In regenerative cycle, a portion of the partially expanded steam is drawn off between the high-and low-pressure turbines. The steal is used to preheat the condensed liquid before it returned to the boiler. In this way, the amount of heat added at the low temperatures is reduced. Therefore the mean effective temperature of heat addition is increased, and cycle efficiency is increased. In the case of an ideal regenerative Rankine cycle, the best result is obtained by heating the feed-water to a temperature equal to the saturation temperature corresponding to the boiler pressure.

The one regenerative Rankine basic cycle is composed of the following seven processes.

12-13 isentropic compression
13-1 isobaric heat addition
1-2 isentropic expansion
2-3 isentropic heat addition
3-4 isentropic expansion
4-5 isentropic expansion
5-6 isentropic expansion
6-7 isentropic expansion
7-8 isobaric heat removing
8-9 isentropic compression
9-10 isentropic compression
10-11 isentropic compression

Applying the mass balance and the First law of thermodynamics of the open system to each of the thirteen processes of the regenerative Rankine cycle and the full formula display in Excel:

$$m_1=m_{13}= m_2 \quad (4.8)$$

$$m_2=m_3=m_4 \quad (4.9)$$

$$m_{12}= m_{11}+m_{10}+m_9 \quad (4.10)$$

$$m_{12}=m_{13} \quad (4.11)$$

$$Q_{13,12} = 0 \quad (4.12)$$

$$W_{13,12} = m_{12}(h_{13}-h_{12}) = m_{12}\, v_{12}(p_{13}-p_{12}) \quad (4.13)$$

$W_{1,13} = 0$ (4.14)

$Q_{1,13} - 0 = m_{13}(h_1 - h_{13})$ (4.15)

$Q_{1,2} = 0$ (4.16)

$W_{1,2} = m_2(h_1 - h_2)$ (4.17)

$W_{2,3} = 0$ (4.18)

$Q_{2,3} - 0 = m_3(h_3 - h_2)$ (4.19)

$Q_{3,4} = 0$ (4.20)

$W_{3,4} = m_4 (h_4 - h_3)$ (4.21)

$Q_{4,5} = 0$ (4.22)

$W_{4,5} = m_5 (h_5 - h_4)$ (4.23)

$Q_{5,6} = 0$ (4.24)

$W_{5,6} = m_6 (h_6 - h_5)$ (4.25)

$Q_{6,7} = 0$ (4.26)

$W_{6,7} = m_{6,7}(h_7 - h_6)$ (4.27)

$W_{7,8} = 0$ (4.28)

$Q_{7,8} - 0 = m_8(h_8 - h_7)$ (4.29)

$Q_{9,8} = 0$ (4.30)

$W_{9,8} = m_8(h_9 - h_8) = m_8 v_8(p_9 - p_8)$ (4.31)

$Q_{9,10} = 0$ (4.32)

$W_{9,10} = m_9(h_{10} - h_9) = m_9 v_9 (p_{10} - p_9)$ (4.33)

$Q_{10,11} = 0$ (4.34)

$W_{10,11} = m_{10}(h_{11} - h_{10})\ m_{10} v_{10}(p_{11} - p_{10})$ (4.35)

The network (W_{net}), Which is also equal to net heat (Qnet), is (4.36)

$W_{net} = W_{1,2} + W_{3,4} + W_{4,5} + W_{5,6} + W_{6,7}$ (4.37)

The thermal efficiency of the cycle is (4.38)

$\eta = W_{net}/Q_{1,13}$ (4.39)

Because of reversible cycle the exergy power output equals of power output of reversible cycle.

$\Psi_1 = m_{dot}(h_1 - h_o) - T_o(S_1 - S_0)$ $\Psi_2 = m_{dot}(h_2 - h_o) - T_o(S_2 - S_o)$ $\Delta\Psi = m_{dot}(h_2 - h_1) - T_o (S_2 - S_1) = m_{dot}(h_2 - h_1)$

$\Psi_3 = m_{dot}(h_3 - h_o) - T_o(S_3 - S_o)$ $\Psi_4 = m_{dot}(h_4 - h_0) - T_o(S_4 - S_0)$ $\Delta\Psi = m_{dot}(h_4 - h_3) - T_o(S_4 - S_3) = m_{dot} (h_4 - h_3)$

$\Psi_5 = mdot(h_5 - h_o) - T_o(S_5 - S_o)$ $\Psi_6 = mdot(h_6 - h_o) - T_o(S_6 - S_o)$ $\Delta\Psi = m_{dot} (h_6 - h_5) - T_o(S_6 - S_5) = m_{dot}(h_6 - h_5)$

$\Psi_7 = m_{dot}(h_7 - h_o) - T_o(S_7 - S_o)$ $\Psi_8 = mdot(h_8 - h_o) - To(S_8 - S_o)$ $\Delta\Psi = m_{dot}(h_8 - h_7) - T_o(S_8 - S_7) = m_{dot}(h_8 - h_7)$

$\Psi_9 = m_{dot}(h_9 - ho) - T_o(S_9 - S_0)$ $\Psi_{10} = m_{dot}(h_{10} - h_o) - T_o(S_{10} - S_9) = m_{dot}(h_{10} - h_9) - T_0(S_{10} - S_9) = m_{dot}(h_{10} - h_9)$

$$\Delta\Psi = \sum(H - TOS)e - (H - TOS)i = \sum(He - Hi) \quad (4.40)$$

Irreversible cycle the exergy power output not equals of power output of reversible cycle.

$\Psi_1 = m_{dot}(h_1 - h_o) - T_o(S_1 - S_0)$ $\Psi_2 = m_{dot}(h_2 - h_o) - T_o(S_2 - S_o)$ $\Delta\Psi = m_{dot}(h_2 - h_1) - T_o(S_2 - S_1)$

$\Psi_3 = m_{dot}(h_3 - h_o) - T_o(S_3 - S_o)$ $\Psi_4 = m_{dot}(h_4 - h_0) - T_o(S_4 - S_0)$ $\Delta\Psi = m_{dot}(h_4 - h_3) - T_o(S_4 - S_3)$

$\Psi_5 = mdot(h_5 - h_o) - T_o(S_5 - S_o)$ $\Psi_6 = mdot(h_6 - h_o) - T_o(S_6 - S_o)$ $\Delta\Psi = m_{dot}(h_6 - h_5) - T_o(S_6 - S_5)$

$\Psi_7 = m_{dot}(h_7 - h_o) - T_o(S_7 - S_o)$ $\Psi_8 = mdot(h_8 - h_o) - To(S_8 - S_o)$ $\Delta\Psi = m_{dot}(h_8 - h_7) - T_o(S_8 - S_7)$

$\Psi_9 = m_{dot}(h_9 - ho) - T_o(S_9 - S_0)$ $\Psi_{10} = m_{dot}(h_{10} - h_o) - T_o(S_{10} - S_9) = m_{dot}(h_{10} - h_9) - T_0(S_{10} - S_9)$

$$\Delta\Psi = \sum(H - TOS)e - (H - TOS)i = \sum(He - Hi) - To(Se - Si) \quad (4.41)$$

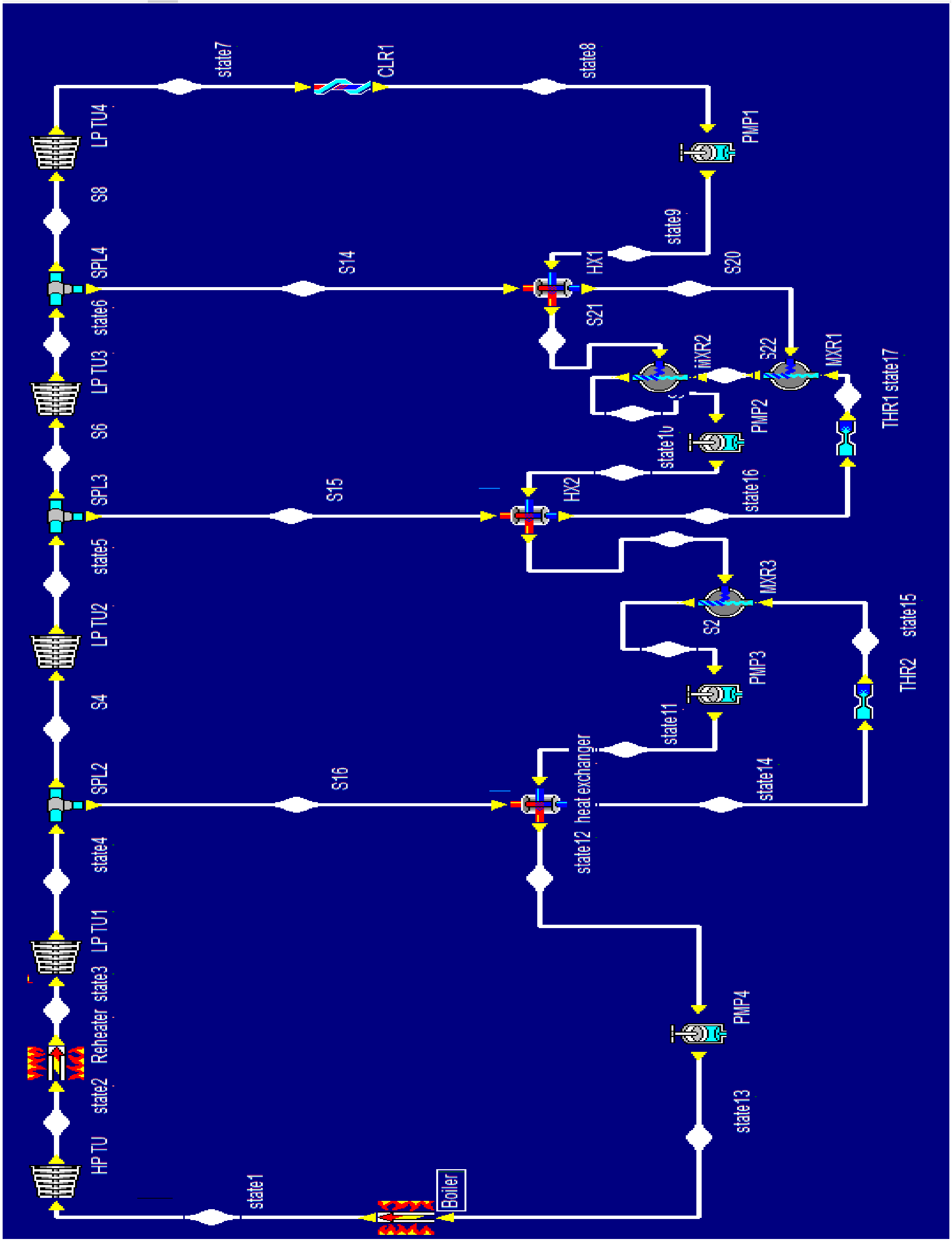

Figure4. 1 Steam cycle model

Table4. 1 Steam cycle state description

State	Description	State	Description
1	steam boiler outlet/Hp-turbine inlet	11s	outlet of mixture/inlet of pump 3
2	Hp -turbine outlet/intermediate super heater inlet	11	exhaust of pump3/inlet of heat exchanger
3	Intermediate super heater outlet/Lp-turbine inlet	12	exhaust heat exchanger/inlet of pump
4	Lp-turbine exhaust / inlet the first splitter	13	exhaust of pump 4/inlet of boiler
S4	splitter outlet/ inlet LP-turbine	14	heat exchanger outlet/inlet pressure reduced
5	Lp-turbine exhaust / inlet the second splitter	15	outlet of pressure reduced/inlet of mixture
S6	second splitter outlet/inlet LP-turbine	16	heat exchanger outlet/inlet pressure reduced
6	exhaust LP-turbine/inlet third splitter	17	heat exchanger outlet/inlet pressure reduced
S8	third splitter outlet/ inlet LP-turbine		
7	Lp-turbine exhaust/ condenser inlet		
8	condenser exhaust/ pump inlet		
9	pump outlet/ FW mix with little hot water that come to third splitter		
S21	Hx1 exhaust/ inlet to mixture		
S22	outlet of mixture /inlet of pump 2		
10	exhaust of pump2/inlet of second FW mix		

4.5. Looking the best profit with given test limitations

The representation model has four different parameters in reasonable range of values to optimize profit are the following.

1. Mass flow to the cooling tower, CT, state 13
   - The minimum is 0 and the maximum is the fraction that corresponds to the difference between the heat demand in the grid and heat production capacity.
2. The pressure drop after the high pressure turbine, T[HP], state 2
   - The pre-determined state 6 decides the minimum pressure in state 2. The minimum pressure in state 2 is the minimum pressure for state3. Corresponding to an isentropic rise from state 6 to temperature for state 3. The maximum pressure is the pressure for the steam boiler outlet.
3. Mass flow through the district heating grid heaters, DH, state 6 and 9
   - The minimum mass flow fraction is 0 and the maximum is what's left from number 1.
4. Pressure and the following characteristics in the drain that preheats the water before the feed water tank, FW, state 4
   - The minimum pressure for the drain to the second pre heater is the minimum pressure for state 6. The maximum pressure is the pressure for the steam boiler out let. The mass flow in the pre heater drains is what's left from number 1 and 3.

The pre-determined state and conditions are illustrated in Table 4.2.

Table4. 2 Pre-determined states and range limit

State	Description	pressure [Kpa]	Temperature [^oC]	Mass flow [fraction]	Range limit
1	Steam boiler outlet	4000	250.4	1	
2	super heater outlet				Pressure [618-4000]
3	super heater inlet	618			
4 and 7	pre-heaters				pressure [500-4000]
6	Lp-turbine outlet	260	120		Mass flow [0-1]

4.6. Gross energy production and profit of Adama waste to energy plant.

Gross steam production is calculated with the efficiencies calculated in a combustion model. The gross steam production determines with the thermal and electric efficiencies the production of heat and electricity production. The total profit is calculated with the current prices for heat and electricity. The highest gross profit from results in the best set up of the tested parameters.

4.7. Parameter for analysis of the waste-to-energy power plant for Adama

The selection of components for a Waste-to-Energy plant there is a number of parameters and conditions to consider. This is a master thesis with a limited timeframe, most components have been chosen by help of experts and consultants especially the Cambridge and EEPCo in their respective areas.

4.8. Waste-to-energy power plant working time

It is more appropriate to find a preferable system that minimizes unplanned downtime. A general requirement of operation is around 8000 hours per year where most of the downtime is planned during the summer when the supply of waste is low.

4.8.1. Waste-to-energy *plant Waste accumulation*

The initial and more important issue is the accumulation of municipal solid waste (MSW). A yearly 40,200-50,00 tone needs a proper treatment system.

4.6.2. Waste composition

Selection of incineration method is influenced by the variation in energy content, moisture, toxic materials and particle size. However, incineration methods that handle large variations are often more expensive. It also doesn't require preparatory treatment of waste. Due to the variations in energy content, it is important to dimension the components to withstand peak temperatures higher than the regular operation temperature.

4.8.3. Environmental regulations

If the design selection is to use a waste recovery solution, like incineration, there are EU directives on emissions that need to be taken into account. The levels of CO_2, NO_x, SO_x, TOC, VOC and GHG required fulfilling the demands of the directives. In order to ensure that the emissions are kept below the regulation values, one needs to have a certain safety margin to compensate for the fuel variations.

4.8.4. Matching the solution into the Adama city energy system

The proposed solution required to meet the demands set by the electrical output, mainly in terms of pressure and temperature. This puts restrictions on the turbine output.

4.8.5. Economy

The difference in price between heat and electricity must be taken into account when designing the plant. The ideal output ratio between heat and electricity is calculated to maximize profit.

After the theoretical design is done its economic feasibility must be discussed with professionals responsible for similar projects, so that the chosen components do not lead to unnecessary investment costs.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1. The energy result value determined from MSW and waste similar to MSW

$$\mathbf{50,000}\left(\frac{t}{a}\right)\boldsymbol{x}\mathbf{9500}\left(\frac{MJ}{1}\right) = \mathbf{427,500,000}\left(\frac{MJ}{a}\right) \tag{5.1}$$

$$\mathbf{427,500,000}\left(\frac{MJ}{a}\right) = \mathbf{15.06}\boldsymbol{MW} \tag{5.2}$$

15.06 MW is the thermal power embedded in the waste and available for the production of electricity and heat. As show below the calculation of highlights the electricity production using this thermal power in according to the study of Cambridge gas turbine.

$$\boldsymbol{Efficiency\ of\ a\ GE\ gas\ turbine}: \sim\mathbf{46\%}(\mathbf{90\%}\ \boldsymbol{plant\ factor}\ (\boldsymbol{availability}) \tag{5.3}$$

$$\mathbf{15.06}\boldsymbol{MWx}\mathbf{46\%} = \mathbf{6.9276}\boldsymbol{MW\ average\ energy\ output} \tag{5.4}$$

$$\mathbf{15.06}\boldsymbol{MWx}\mathbf{8,760}\left(\frac{hr}{a}\right)\boldsymbol{x}\mathbf{0.90} = \mathbf{118.733}\boldsymbol{GWh\ per\ year} \tag{5.5}$$

This analysis shows as there is huge energy potential in the waste of Adama, 118.733GWh, which is lost to the landfill at present.

5.1.1. Working time

In this feasibility study design, as well as most new Waste-to-Energy plant designs, all calculations are done for 8000 production hours per year.

5.1.2. Raw material Supply

The current yearly waste accumulation is based on the data collected in 2007 EC was 40,200 tone, and is expected to grow 50,000 tones over the coming year. There is also a reliable source of straw that could be used to balance out any gaps in the waste supply. Since the planned operation time used in calculations will be 8000 hours, the hourly waste feed will be 2,283.105 kg/h.

The capacity of waste storage bunker designed to hold enough waste for three days of production. The waste density is approximated to 11.415 kg/m^3.

The calorific value is 2.6 MWh/tone pure waste or 2.8 MWh/tone with mixed in straw, but these values depend on the waste composition used in the calculation.

5.2. Calculation models of the feasibility study results

WTE plant feasibility study has been done knowing that the waste composition has not yet been analyzed for the Adama area. With this in mind a sort of multistep dynamic model has been produced to be able to change all the results depending on what waste composition is specified. The waste composition used for this draft of the study is from a similar project in Addis Ababa, Ukraine. Using the waste composition in a WTE simulation program provided by Avfall Sverige the elemental composition is gained.

Using this information and theoretical combustion chemistry, an Excel –model has been made to calculate the heat generation and flue gas content. A majority of the combustion energy is converted to a flow of saturated steam at 250^{0}C, 4000 kpa, which is then used in CYCLEPAD steam cycle model. This model optimizes the output of thermal and electrical power to maximize profit using current Ethiopian energy prices, while delivering thermal power according to the Adama district heating grid specifications. The calculated flue gas flow is used in WTE simulation program to obtain emitted flue gases after treatment.

5.3. Waste composition disposed in Adama

There were no conclusive studies on the Adama waste composition. However, In this feasibility study have information of waste composition for four kebeles which are most prone to Solid waste problems were purposively selected for having large number of industries, business places and population size. This data collected by through interview and practical observation by Mengist Hailemariam for he's study which was solid waste management for Adama. So that the rest of the waste composition assumed similar and shown on Figure 5.1 and Figure 5.2.

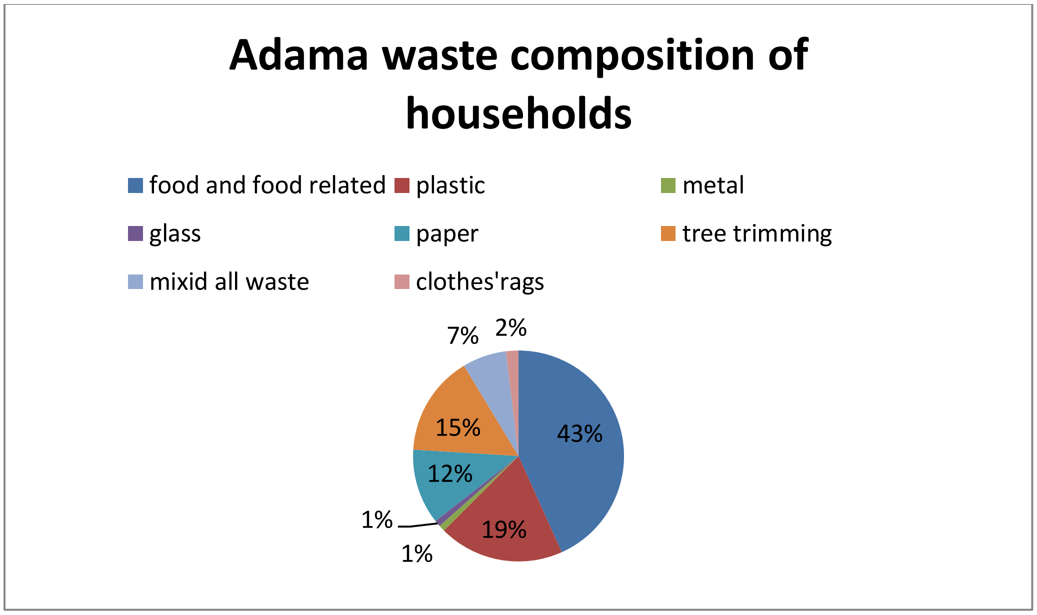

Figure5. 1 Adama waste composition households

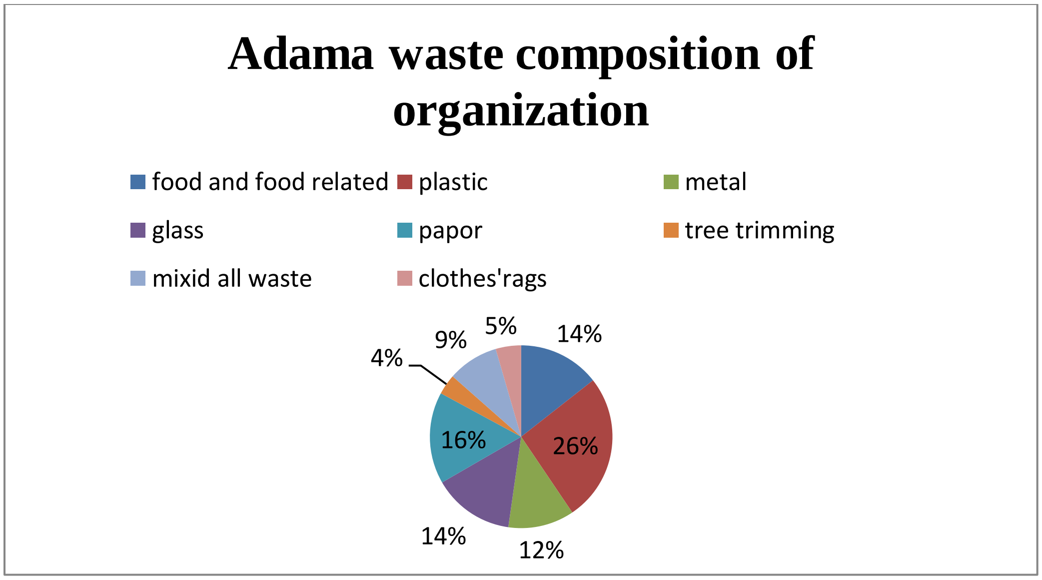

Figure5. 2 Adama waste Composition source industry

5.3.1. Adama waste elemental composition

Elemental composition simulation shows a relatively energy dense substance, which is likely to have a calorific value of around 3 MWh/tone. This value is taken by assumption of waste similarity Addis Ababa and Chisinau, also the moisture content is 47% (Cambridge,2017) the results shown in table 5.1.

Table5. 1 Elemental Composition

Main components			**Ash composition**	Weight % Ashes
Moisture Content	Weight %	47.000	**Na_2O**	8.277
Ash Content	Weight % dry substance	24.229	**k_2oO**	8.415
Elemental Composition			**CaO**	39.312
Carbon	Weight % dry, excl ash	59.721	**MgO**	6.089
Hydrogen	Weight % dry ,excl ash	8.547	**SIO_2**	20.575
Oxygen	Weight % dry, excl ash	29.063	**Al_2O_3**	6.357
Nitrogen	Weight % dry, excl ash	1.919	**Fe_2O_3**	6.633
Sulfur	Weight % dry, excl ash	0.223	**TiO_2**	0.226
Halogen			**MnO**	0.288
Chlorine	Weight % dry, excl ash	0.556	**BaO**	0.058
Fluorine	g/tone dry	244.355	**SnO**	0.049
Bromine	g/tone dry	4.125	**P_2O_3**	2.904

Notice

In reality, the moisture content is expected to be above this value, which would result in a lower heat generation value due to the lower combustion temperature. To counteract this, a set of combustion temperature scenarios will be set up when calculating the flue gas heat transfer.

5.3.2. Combustion Heat Generation

Now we multiplied elemental fractions with waste feed flow, which is obtain by dividing the total waste generation in to time, resulting in an elemental feed to the combustion grate. Exothermic reaction is the important one and it provide the positive thermal impact value, while heating the inert elements represents most of the negative values.

Calculating the amount of energy change from waste to steam is done in many steps. All the solution used, apart for some of the authors' assumptions, can be found in Henrik Alvarez energy engineering literature.

5.3.3. Determining the elemental composition of the waste of Adama

This is given by the waste to energy simulation software, where a given waste composition yields an elemental composition. See in appendix, the essential elemental contents are the carbon,T hydrogen, oxygen, nitrogen and sulfur. The rest are used to calculate the heat loss in from the ashes that are removed from the furnace.

5.3.4. Calculating the necessary combustion air supply

The required air supply for the combustion process can be summarized, with a slight simplification, as the oxygen necessary for complete combustion of the dry, ash-free fraction of the waste is singled out and the combustible elemental fractions are determined. These needed different amounts of oxygen. In Table 5.2 show the elemental composition of the combustible fuel.

Table5. 2 Elemental Composition of the combustible fuel gives the theoretical air supply needed for combustion

Main components	Weight %			Elements			
Moisture	47.000	0.470		Carbon	6.88426513	0.06884265	
Ash (of dry)	24.229	0.242		Hydrogen	0.985360231	0.0098536	
Dry ash free	47.808	0.478		Oxygen	3.350201729	0.03350202	
				Nitrogen	0.221210375	0.0022121	
Elemental composition air				Sulfur	0.025706052	0.00025706	
Nitrogen	75.54	0.7554					
Oxygen	24.46	0.2446		Air supply			
				O_2	N_2		
Elemental analysis				Kmol/kg fuel		kg/kg of fuel	
Carbon	3.1925072	0.03192507		0.002662824	0.010005764	0.08512968	0.29
Hydrogen	0.45694524	0.00456945		0.00114121	0.004299712	0.03655331	0.12
Oxygen	1.55365994	0.0155366		-0.00048415	-0.00182133	-0.0155389	-0.051
Nitrogen	0.10259366	0.00102594			0	0	0
Sulfur	0.01198847	0.00011988		1.15274E-05	1.15274E-05	0.00011527	0.0004
			sum	0.003331412	0.012495677	0.10625937	0.35
				Theoretical air supply		0.45591	kg/kg of fuel

Then determining the theoretical airflow, the real airflow and flue gas flow is calculated. The real airflow is calculated by multiplying the theoretical one with the specific airflow factor, n, which is 1.5-1.6 for waste. This also gives the air surplus, I_o, from which the excess oxygen can be derived.

5.3.5. Using fuel and air data to calculate heat generation

Elemental composition of the waste and the air flow are the two essential factors when calculating the heat generation. The flow of waste is 5.70777tones/hour=1.5854~1.6 kg/s. To counteract the heat generation from the combustion of the waste, the negative processes are:

- Heating inert ashes, moisture, nitrogen and excess oxygen
- Vaporization of the moisture
- Reaching the waste's combustion temperature, which is considered to be 250^0C

The net heat generation is then calculated by multiplying the waste fractions with the total flow, as well as the thermal impact it has on the process.

Before doing that, however, the specific heat capacities of the excess air and the ashes need to gathered specific heat capacities of N and O are gathered from literature: $C_p[N_2]$=1.04 kJ/(kg*k), $C_p[O_2]$=0.919 kJ/(kg*k), and C_p[Ash]=0.814 kJ/(kg*k) (Explained below)

The inert ashes elemental composition is used for the most essential ash components and their individual heat capacities are multiplied with their elemental fractions, showed Table 5.3. it was not possible to find heat capacities for the ash compounds. Instead they were estimated using the specific heat capacity of every element, and the molar mass fraction of the molecules.

Table5. 3 C_p-estimations, the specific heat capacities for elemental components give C_p for each

	Weight % of ash		of total waste	Cp kJ/kg-k
Na2O	8.276	0.082	0.0126	1.229
k2O	8.415	0.084	0.0128	0.784
CaO	39.311	0.393	0.06	0.714
MgO	6.089	0.06	0.009	0.98
SiO2	20.575	0.205	0.031	0.817
Al2O3	6.357	0.063	0.01	0.909
Fe2O3	6.632	0.066	0.01	0.591
Total	98.658	0.957	0.146	0.814

After the required heat capacities have been gathered the heat generation can be determined. Heat generated in the furnace is determining through the thermal impact that every waste component has on the process. See Table 5.4. In this calculation process the thermal impact of every individual process, multiplied by its flow, is added up to get a summarized heat generation. The processes are combustion, vaporization and heating of inert compounds. This summarized heat generation in can be compared to the power input from the waste flow to get the incineration grate efficiency, η_{grate}.

Table5. 4 Heat generation results of combustion calculation

Column1	Flow [kg/s]	Thermal contribution [kJ/kg]	Thermal Impact [KJ/s]
Water content	0.816675	-2591.4	-2116.33
Ashes (inert)	0.0244	-69.17	-1.68495
Reaching comb.temp	6.6400	-616.63	-4094.42
Carbon	1.0153	33913	34430.41
Hydrogen	0.1453	142770	20746.77
Nitrogen	0.0326	-945.49	-30.84472
Sulfur	0.0038	10467	39.68040

Excess oxygen	0.8570	-836.29	-716.7005
inert N2	0.340	-945.49	-321.0695
Average Thermal power output [kw]			47935.81
Average Thermal power output [Mw]			47.93581

5.4. The generation flue gas flow

The major part of the flue gases originate from the air flow, Iv, which facilitates combustion. Inside the combustion processes with energy dense fuels the air flow will be almost twice as high, in terms of air mass per fuel mass, compared to waste combustion. This is due to the fact that only around half of the fuel mass is combustible. To calculate the energy transfer in the flue gas, first we have to know the total flue gas flow, gv, is used to calculate the energy transfer in the flue gas.

Recognizing the incoming flow of combustible elements and the theoretical air supply, the real flue gas flow can be calculated. This is done through a number of calculations: Air surplus, I_o, theoretical flue gas flow, g_t, and real flue gas flow, g_v.

5.4.1. Air surplus, l_o

The part of the air supply, where not even the oxygen takes part in the combustion process.

$$l_o = l_v - l_t \quad (5.6)$$

5.4.2. Theoretical flue gas flow, g_t

Theoretical airflow allows the combustion of the combustible elements, Table 5.5 showed which yields the theoretical flue gas flow.

Table5. 5Theoretical airflow Combustible elements

Flue gas from combustion	Kmol/kg fuel	Kmol/s	kg/s	ton/h	Weight %	% with air surplus
CO_2	0.002654409	0.036950314	1.6258138	5.869363884	21%	14%
H_2O	0.004648096	0.064553314	1.16195965	4.194800196	15%	10%
O_2						7%
N_2	0.012523621	0.173939182	4.87029708	17.58229994	64%	67%
SO_2	3.73086E-06	5.18179E-05	0.00326453	0.011785291	0%	0%
Total	0.019829858	0.275494627	7.66133506	27.65824931	100%	100%

5.4.3. Real flue gas flow, g_v

As shown in Equation 5.3 the real flue gas flow is can be obtained by adding the air surplus and flue gas flow.

$g_v = g_t + l_0$ (5.7)

5.4.4. Flue gas flow summary

Calculations of flus gas done, the total flows of the combustion gases as well as the air surplus are obtained. Table 5.6 shows the value in relation to the incoming waste flow as well as the expected hourly flue gas flow, CO_2- flow and the fraction that originates from fossil sources.

Table5. 6 Results of the flue gas flow calculations

Airflow(theoretical)	lt	0.45591	[kg/kg of fuel]
Airflow factor	N	1.55	
Airflow (real)	lv	0.7066605	[kg/kg of fuel]
Air surplus	Lo	0.2507505	[kg/kg of fuel]
Air density	ρ1	1.204	[Kg/m^3]
Air volume	V1	0.58685879	[m^3/kg fuel]
Fuel flow	Qw	1.6	[kg/s]
Fuel gas flow (theoretical	Gt	4.78833438	[kg/kg of fuel]
flue gas flow (real)	Gv	5.03908488	[kg/kg of fuel]
flue gas flow (total)		8.062536	[kg/s]
Hourly flue gas flow (total)		29025.1296	[kg/h]

5.4.5. Flue gas heat capacity

Recognize the composition of the flue gases; the average specific heat capacity can be found using standard C_p –values for each specific gas component. Table 5.7 shows specific heat value, the mid value are determining at certain temperatures that will be relevant to the heat exchange process.

Table5. 7 Average specific Enthalpy and specific heat capacity, C_p

Component		O_2	CO_2	H_2O	SO_2	N_2	Average
weight fraction		0.00926	0.21024	0.1503	0.000	0.62981	
Density	[kg/m3]	1.429	1.977	0.597	3.049	1.251	1.297
C_p	[kJ/Kg-k]	0.919	0.844	1.93	0.64	1.04	1.18325
h[70]	[kJ/kg]	4.6883060	96.052601	7.1607025	0.1461568	64.040832	34.41772
h[90]	[kJ/kg]	6.0278220	123.49620	6.1262199	0.1879159	130.73500	53.314633
h[100]	[kJ/kg]	6.6975801	137.21800	6.8069110	0.2087955	145.26111	59.238481
h[130]	[kJ/kg]	8.7068541	178.38340	8.8489843	0.2714341	188.83945	77.010025
h[160]	[kJ/kg]	10.381249	212.68790	10.550712	0.3236330	225.15473	91.819645
h[168]	[kJ/kg]	56.929430	1166.3530	57.858743	1.7747619	1234.7194	503.52708
h[250]	[kJ/kg]	66.975801	1372.1800	68.069110	2.0879552	1452.6111	1000.38481
h[1400]	[kJ/kg]	93.7661214	1921.05204	95.2967542	2.92313728	1610.000	1763.484

5.4.6. Heat exchange and losses

The heat convert process is where all the flue gas energy is put to use in different steps. When designing the heat converts system between furnace and boiler the goal is to maximize the boiler efficiency, while still operating at sustainable temperatures. The two most essential limitations are set by the furnace heat resistance, which sets the highest temperature, and flue gas treatment requirements, which sets the lowest temperature. Most of time, the flue gas needs to be treated in the temperature range between 130-155^{0}C. Then this, a portion of the remaining flue gas energy content is used for pre-heating combustion air, at between 50-70^{0}C the rest of the energy is released through the chimney.

To demonstrate different possible furnace designs that would lead to different flue gas temperature distributions, a few scenarios of initial heat exchange temperatures have been set up. See Table 5.8. The range of possible temperatures is 250-1400^{0}C, where the lower limit is set by emission regulations and highest limit is the highest theoretical combustion temperature. A portion from the initial temperatures, the temperatures are pre-determined.

The majority of the heat exchange to the steam cycle in the boiler. Then this it enters the flue gas treatment, where the heat between 130-155^{0}C is consider filter losses. Before the gases are release through the chimney, the heat between 130-70^{0}C is used to preheat the combustion air. Since this portion improves the combustion it is not considered a loss.

Table5. 8 Heat exchange scenarios From T=250^{0}C: the minimum allowed furnace temp T=1400^{0}C: the highest theoretical temperature.

Flue Gases	h[160]-case		h[168]case		h: From to Heat gen		h[300]-case	
h Flue gas	505.527	kJ/kg	592.385	kJ/kg	1000.3299	kJ/kg	1763.48	kJ/kg
p Flue gas	11.32	MW	13.5458	MW	47.9358	MW	170.90	MW
Boiler [ΔT] ηboiler	[160-155^{0}C]	η = 80%	[168-155^{0}C]	ηb = 82%	[T spec-155^{0}C]	η = 86%	[1400-155^{0}C]	η = 94.1%
h Boiler	429.69795	kJ/kg	503.52725	kJ/kg	860.830415	kJ/kg	1593.438	kJ/kg
p Boiler	9.622	MW	11.51393	MW	40.74543	MW	154.42	MW
Filter losses	[155-150^{0}C]		[155-130^{0}C]		[155-130^{0}C]		[155-130^{0}C]	
	27.69	kJ/kg	27.69	kJ/kg	27.69	kJ/kg	28.89	kJ/kg
	2.65	MW	2.65	MW	2.65	MW	2.65	MW
Air pre-heat	[130-70^{0}C]		[130-70^{0}C]		[130-70^{0}C]		[130-70^{0}C]	
	7.5101	kJ/kg	7.5101		7.5101		65.5101	kJ/kg
Regained preheat	0.72738	MW	0.7274	MW	0.72738	MW	6.7274	MW
Exhaust	0.84957	MW	0.8496	MW	0.84957	MW	7.37	MW
Total p Boiler	6.84981	MW	8.7417	MW	36.48848		160.73	MW

Comments

These are just the initial values of that used for MECH IN EXCEL, PYTHON, and CYCLEPAD software model uses to calculate the power output. The filtration, pre-heating and exhaust temperatures usually the same, however, the initial temperature will difference according to the calorific value of the waste.

5.5. Steam cycle model in MECH IN EXCEL, PYTHON, and CYCLEPAD

The output from the MECH IN EXCEL, PYTHON, and CYCLEPAD is the theoretically most profitable steam cycle parameter configuration and the energy production with that configuration. According to Equation 5.8 we can determine the initial enthalpy value of the system or the exhaust value of the boiler. With this initial value it is possible to analyze the system in the Rankine cycle.

$$\eta boil = Msteam(h1 - h13)/(Cv\, Mfuel) \quad (5.8)$$

Where

Cv is the thermal impact multiply mass flow rate of waste which give as calorific value of waste.

M_{steam} is the mass flow rate of the steam throughout the system of the cycle.

M_{waste} is the mass flow rate of solid waste material or fuel

5.6. Display results

By using the above data the result is display in CYCLEPAD in the following two ways.

1. The numerical value of reversible cogeneration Rankine cycle result.

Display the diagram and cycle properties results in Figure5.3. The cycle is Rankine heat engine.

Because of reversible cycle the exergy power output equals of power output of reversible cycle.

$$\Delta\Psi = \sum(H - TOS)e - (H - TOS)i = \sum(He - Hi) \quad (5.9)$$

Net exergy power reversible ($\Delta\Psi_{net}$) =37165 KW

Power output for reversible cycle = 37357 KW ~37.35 7MW

Power input for reversible cycle = -191.7 KW~0.1917 MW

Net power output for reversible cycle = 37,165 KW = 37.165 MW

Carnot efficiency for reversible cycle = 38.38%

Thermal efficiency for reversible cycle = 27.38 %

Q-dot in boiler for reversible cycle = 128,727 KW

Q-dot out in condenser for reversible cycle = -98,562 KW

Net Q-dot for reversible cycle=37165 KW

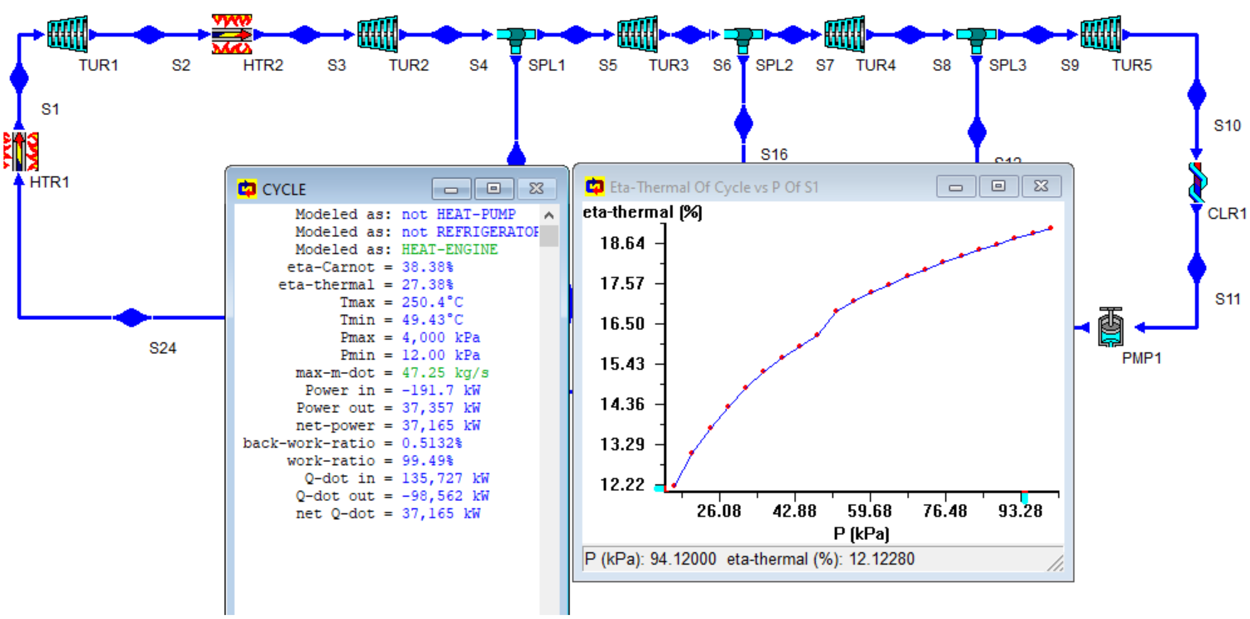

Figure5. 3 The Rankine Cycle result and efficiency diagram

2. Discussion by using sensitive diagrams.

The following diagram describes the cycle performance, the energy input of the system.

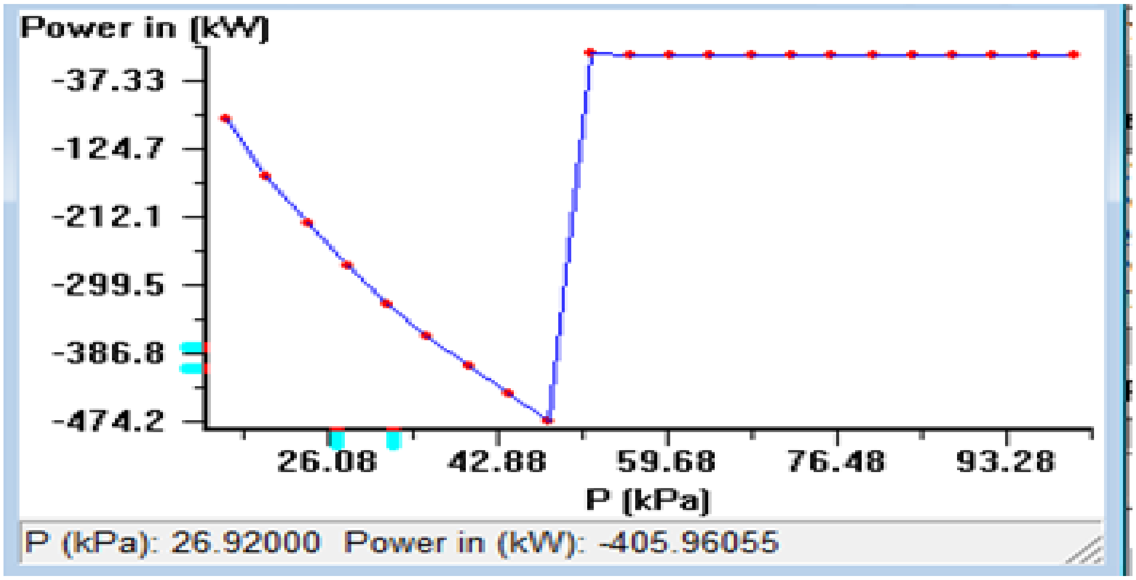

Figure5. 4 Power in of cycle Vs pressure

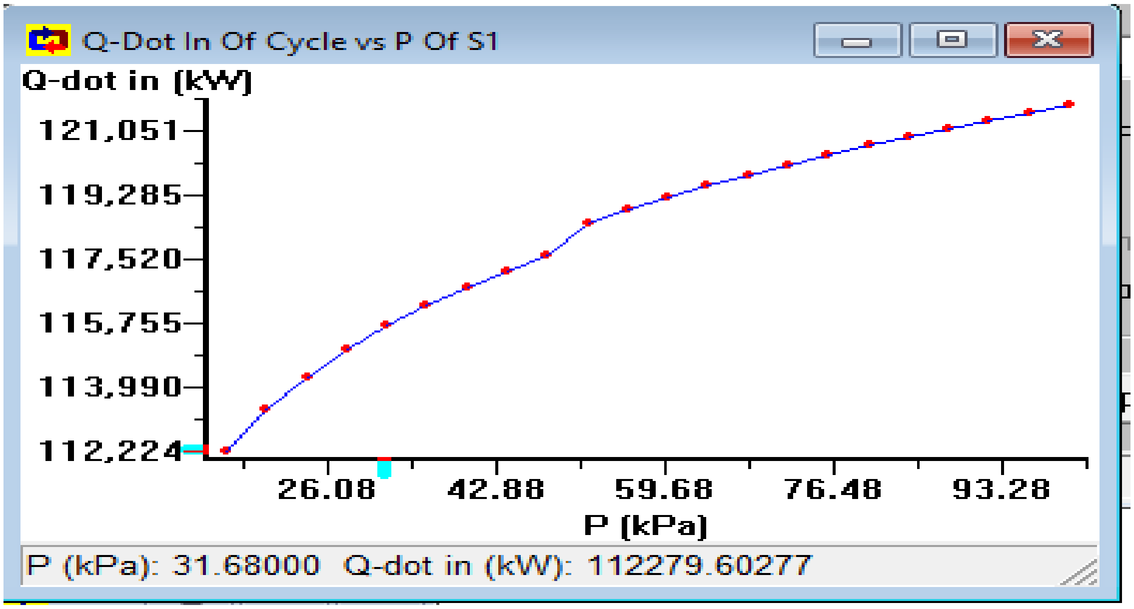

Figure5. 5 Q-dot in of cycle vs Pressure

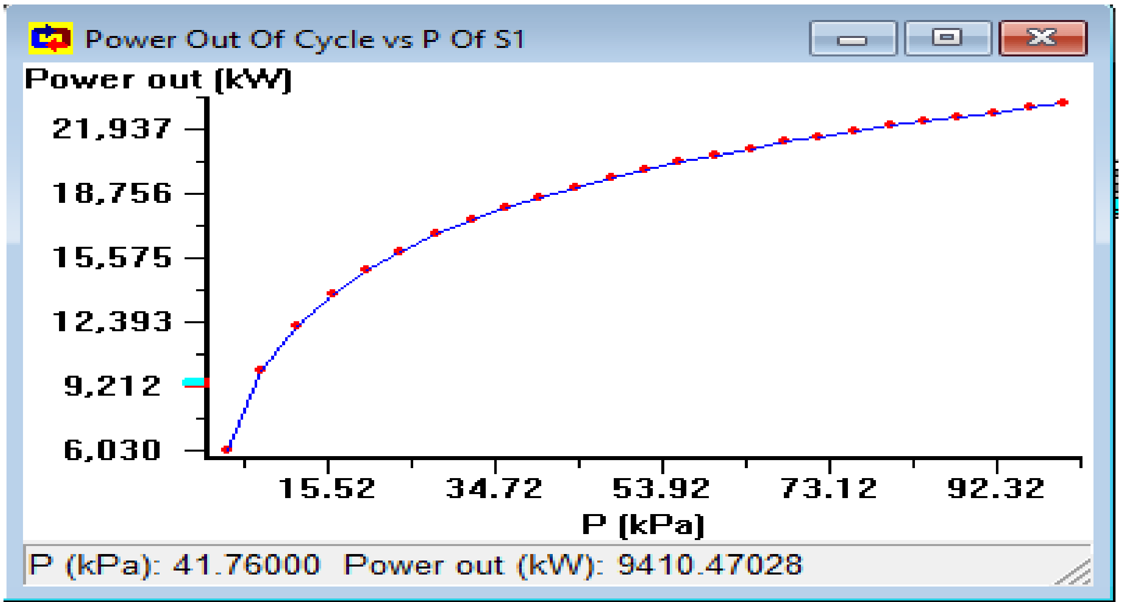

Figure5. 6 Power out of cycle Vs pressure

As Figure 5.4 shows power in of cycle vs. pressure, it is seen that pressure increase, power in of the cycle decrease in the first stage and power in and pressure remain constant at the last stage.

Figure 5.5 tells that heat addition of the cycle increase, enthalpy of the cycle also increase this means heat addition and enthalpy have linear relationship.

From the sensitivity diagram in Figure 5.6 Q-dot in of cycle vs. pressure. It is seen that heat addition of the cycle increase, pressure also increases, at high pressure heat addition of a cycle also high.

From the sensitivity diagram in Figure 5.7 power out of cycle vs. pressure. It is seen that the higher the pressure, the higher the cycle power out the cycle. The pressure is limited due to pump capacity and metallurgical considerations.

5.7. The actual steam cycle result.

From the turbine manufacture Siemens give the efficiency of turbine 85% by using this value, the calculation result of steam cycle and thermal efficiency of cycle vs isentropic efficiency of pump display in Figure 5.7.

Because of irreversible the cycle exergy power output not equal to power output of cycle. The average temperature in Adama T_o =25^{0}C (298k).

$$\Delta\Psi = \sum(H - TOS)e - (H - TOS)i = \sum(He - Hi) - T_o(Se\text{-}Si) \quad (5.10)$$

Net exergy power irreversible ($\Delta\Psi_{net}$) =27485.67 KW

Power output for irreversible cycle = 32,237 KW ~32.237MW

Power input for irreversible cycle = -225.7 KW~0.2257 MW

Net power output for irreversible cycle = 32,011 KW = 32.011 MW

Carnot efficiency for irreversible cycle = 38.38%

Thermal efficiency for irreversible cycle = 23.75%

Q-dot in boiler for irreversible cycle = 134,771 KW

Q-dot out in condenser for irreversible cycle = -102,760 KW

Net Q-dot for irreversible cycle=32,011 KW

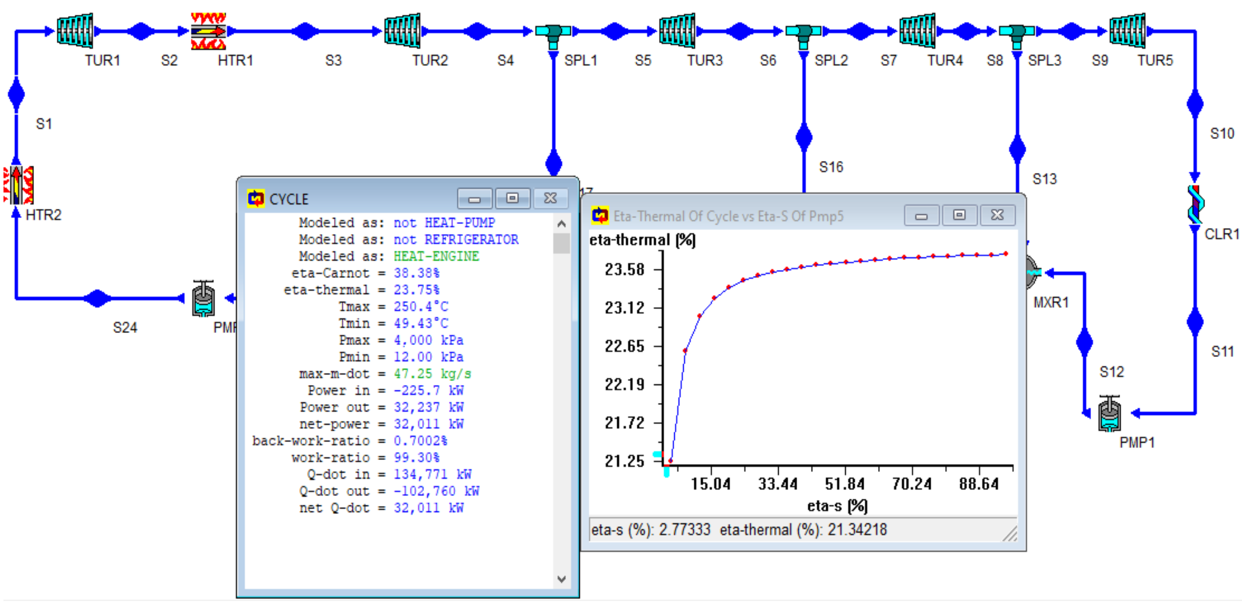

Figure5. 7 actual steam cycle results

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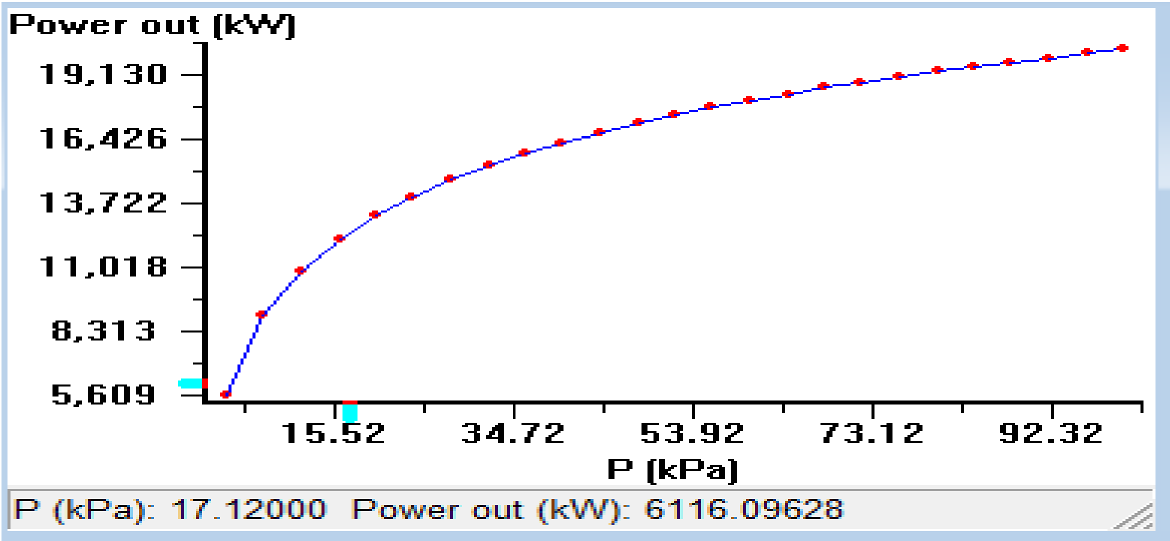


Figure5. 8 power output of cycle vs pressure

Figure 5.9 tells that; Power output increase as pressure increase, but if pressures continuously increase the power output remains constant. However, pressure also have limit due to pump capacity and metallurgical considerations.

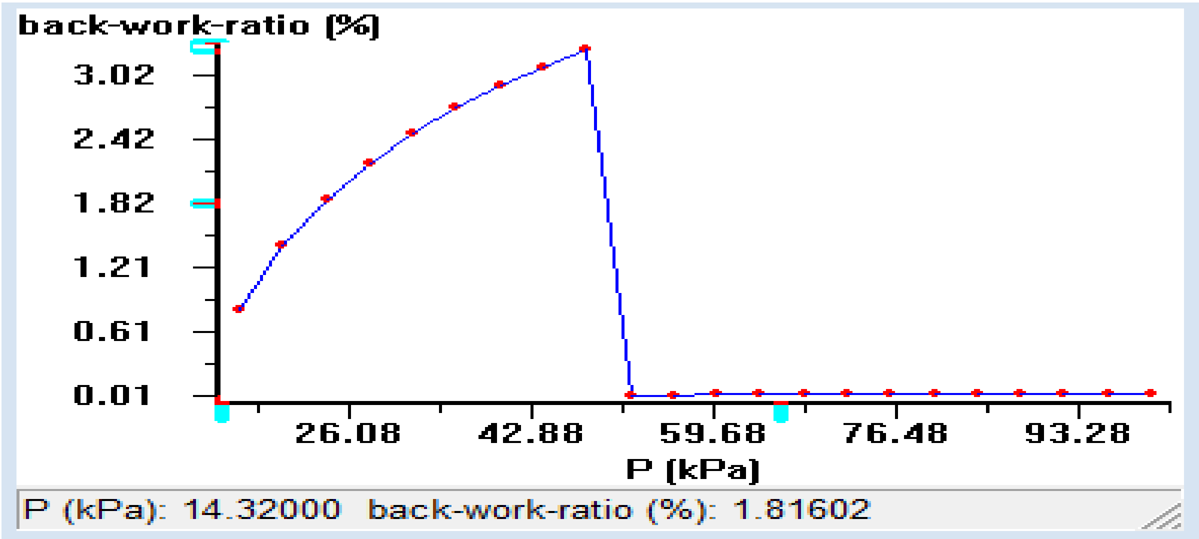


Figure5. 9 Back-work-ratio Vs pressure

As Figure 5.11 shows for small pressure the back-work-ratio increase which is at the first stage of the cycle back-work-ratio is increase. But pressure becomes increase the back-work-ratio decrease. At the last stage smaller values of back-work-ratio with constant value but pressure increase.

5.8. Result cross comparison by MECH IN EXCEL, and PYTHON

The reversible and irreversible cycle result also displays in MECH IN EXCEL, and PYTHON were displayed results in Table 5.9, Table 5.10, and Table 5.11 the full calculation and python code displayed in appendix 1. This calculation done based on Rankine cycle principle which means analyzed on Ideal and Real Rankine cycle.

Table5. 9 Cycle result in MECH IN EXCEL

Work required and work done			
work done in turbine one 1s	w_t1s	128.953072	KJ/kg
work done in turbine one 1a	w_t1a	109.610112	KJ/kg
efficiency of turbine and pump	Effi	0.85	Value
work done in first stage turbine 1s	w_st1s	185.249418	KJ/kg
work done in first stage turbine 1a	w_st1a	157.462005	KJ/kg
work done in first stage turbine 2s	w_st2s	168.479813	KJ/kg
work done in first stage turbine 2a	w_st2a	143.207841	KJ/kg
work done in first stage turbine 3s	w_st3s	115.025625	KJ/kg
work done in first stage turbine 3a	w_st3a	97.7717813	KJ/kg
work done in first stage turbine 4s	w_st4s	205.915429	KJ/kg
work done in first stage turbine 4a	w_st4a	175.028114	KJ/kg
work required for first pump 1s	w_pt1s	0.02112088	KJ/kg
work required for first pump 1a	w_pt1a	0.02484809	KJ/kg
work required for second pump 2s	w_pt2s	0.07802298	KJ/kg
work required for second pump 2a	w_pt2a	0.09179174	KJ/kg
work required for third pump 3s	w_pt3s	0.18509055	KJ/kg
work required for third pump 3a	w_pt3a	0.21775359	KJ/kg
work required for fourth pump 4s	w_pt4s	3.86669862	KJ/kg
work required for fourth pump 4a	w_pt4a	4.5490572	KJ/kg
work required total	w_rtotal	4.88345062	KJ/kg
work net	w_net	678.196403	KJ/kg
work required for pump total ideal	w_rnet ideal	4.88345062	KJ/kg
work total ideal	w_net ideal	803.623357	KJ/kg
work done actual total	w_total	683.079854	KJ/kg
work net ideal	w_total net ideal	798.739907	KJ/kg
mass flow rate	dm_dt	47.25	kg/s
power output ideal	power ideal	37740.4606	Kw
power output actual	Power	32044.7801	KW
power output actual	Power	32.0447801	MW

Result of reversible (ideal) steam cycle which is isentropic process, in MECH IN EXCEL.

Net exergy power reversible ($\Delta\Psi_{net}$) =37,740.4606 KW

Power output for reversible cycle = 37971.20 KW ~37.971MW

Power input for reversible cycle = -230.74 KW~0.230 MW

Net power output for reversible cycle = 37,740 KW = 37.740 MW

Result of irreversible (actual) steam cycle which is isentropic process, in MECH IN EXCEL.

Net exergy power irreversible ($\Delta\Psi_{net}$) =27485.67 KW

Power output for irreversible cycle = 32,275 KW =32.275MW

Power input for irreversible cycle = -230.74 KW= -0.2307 4MW

Net power output for irreversible cycle = 32,044 KW = 32.044 MW

As Table 5.10 shows the result that gets in CYCLEPAD is correct because the difference between CYCLEPAD and MECH IN EXCEL are less than one. Also when compere the exergy power output it is similar 98 % which is this also shows that the calculation done by CYCLEPAD is correct.

Table 5.10 Steam cycle result in PYTHON

Reversible steam cycle in PYTHON	Value	Unit
Total work done of the turbine in ideal	811.27	KJ/kg
Total work required for pump in ideal	4.12	KJ/kg
Network output of the plant in ideal	807.15	KJ/kg
Power output of the plant in ideal	38137.99	KW
Power output of the plant in ideal	38.14	MW

Net exergy power reversible ($\Delta\Psi_{net}$) =38,137.4606 KW

Power output for reversible cycle = 38,332.5075KW =38.332MW

Power input for reversible cycle = -194.67 KW=0.19467 MW

Net power output for reversible cycle = 38137.4606 KW = 38.137 MW

Table 5.11 Steam cycle result in PYTHON

Irreversible steam cycle in PYTHON	Value	Unit
Total work done of the turbine	689.58	KJ/Kg
Total work required for pump	4.12	KJ/Kg
Network output of the plant	684.74	KJ/Kg
Thermal efficiency for cycle	55.22	%
power output of the plant	32353.75	KJ/Kg
Power output of the plant in MW	32.353	MW

Net exergy power irreversible ($\Delta\Psi_{net}$) =28985.67 KW =28.985MW

Power output for irreversible cycle = 32,582.655 KW =32.275MW

Power input for irreversible cycle = -194.67 KW= -0.19467MW

Net power output for irreversible cycle = 32,353.75 KW = 32.353 MW

As Table 5.11, and Table 5.12 shows the result that gets in CYCLEPAD is correct because the difference between CYCLEPAD, MECH IN EXCEL, and PYTHON are less than ten. Also when compere the exergy power output it is similar 95 % which is this also shows that the calculation done by CYCLEPAD is correct.

5.9. Solar assisted solid waste to energy power plant

The solar assisted part in Solid waste to energy power plant, this part takes a long time in this project. Because the idea is new and need a lot of literature review but there is no literature available in this title. After so many discussion with several Rappi energy project consultants and workers. Finally we conclude the following possibility.

The wet content of solid waste in developing country is very high when compere to developed country. Waste to energy power plant banker can hold waste for three up to five days and maximum seven days. So holding wastes in banker not enough to reduce wet content. Because keeping waste more than seven day it catches fire in the banker which is unavailable to produce energy. So reduction of wet from waste is important, the wet content can be reduced by using solar system. In this feasibility study assume three types of drying process outside of solid waste banker.

1. The first assumption is build solid waste banker outside solid waste to energy plant. After that allowed the radiation come from sun directly through roof which means the solid waste banker roof material made by radiation transmitter material.

2. The second assumption is similar to the first one, but in this time we use solar dryer which means in addition to radiation transmitter use the solar air heater and this hot air allowed to circulate in the solid waste bunker. At one end hot air plow and the other end cold air suck. By doing this in this feasibility study assumed that make better dryer when compere to the first one.
3. The third assumption is similar to the second one; however in this time we use water instead of air. Additionally in this type of dryer pipe is need, which is the hot water need to circulate inside solid waste deposition or in the building of waste banker. In this type of dryer we need more area and parabolic solar collector. By using this type of dryer we can dry more preferable waste. According to our assumption this type of dryer more absorb wet content in solid waste material.

The wet content of solid waste in Ethiopia has 47% according to the researcher of Cambridge industry, and Ethiopian electric power cooperation (EEPCo). Now in order to calculate the solar assisted part assume the wet content of solid waste was 36%, this assumption is accepted because of the Chisinau waste wet content is 36%. The calculation made the above remain the same but the wet content was vary so the result displayed below.

Elemental composition simulation shows a relatively energy dense substance, which is likely to have a calorific value of around 3 MWh/tone. This value is taken by assumption of waste similarity Addis Ababa and Chisinau, also the moisture content is 47% (Chisinau,2012) the results shown in table 5.12.

Table5. 12 Solar assisted elemental Composition

Main components			**Ash composition**	Weight % Ashes
Moisture Content	Weight %	36.904	**Na_2O**	8.277
Ash Content	Weight % dry substance	24.229	**k_2oO**	8.415
Elemental Composition			**CaO**	39.312
Carbon	Weight % dry, excl ash	59.721	**MgO**	6.089
Hydrogen	Weight % dry ,excl ash	8.547	**SIO_2**	20.575
Oxygen	Weight % dry, excl ash	29.063	**Al_2O_3**	6.357
Nitrogen	Weight % dry, excl ash	1.919	**Fe_2O_3**	6.633
Sulfur	Weight % dry, excl ash	0.223	**TiO_2**	0.226
Halogen			**MnO**	0.288
Chlorine	Weight % dry, excl ash	0.556	**BaO**	0.058
Fluorine	g/tone dry	244.355	**SnO**	0.049
Bromine	g/tone dry	4.125	**P_2O_3**	2.904

5.9.1. Solar assisted calculating the necessary combustion air supply

The required air supply for the combustion process can be summarized, with a slight simplification, as the oxygen necessary for complete combustion of the dry, ash-free fraction of the waste is singled out and the combustible elemental fractions are determined. These needed different amounts of oxygen. In Table 5.13 show the elemental composition of the combustible fuel.

Table5. 13 Elemental Composition of the combustible fuel gives the theoretical air supply needed for combustion

Main components	Weight %			Elements			
Moisture	36.904	0.369		Carbon	6.88426513	0.06884265	
Ash (of dry)	24.229	0.242		Hydrogen	0.985360231	0.0098536	
Dry ash free	47.808	0.478		Oxygen	3.350201729	0.03350202	
				Nitrogen	0.221210375	0.0022121	
Elemental composition air				Sulfur	0.025706052	0.00025706	
Nitrogen	75.54	0.7554					
Oxygen	24.46	0.2446		Air supply			
				O_2	N_2		
Elemental analysis				Kmol/kg fuel		kg/kg of fuel	
Carbon	3.1925072	0.03192507		0.002662824	0.010005764	0.08512968	0.280092219
Hydrogen	0.45694524	0.00456945		0.00114121	0.004299712	0.03655331	0.12026513
Oxygen	1.55365994	0.0155366		-0.00048415	-0.00182133	-0.0155389	-0.051112392
Nitrogen	0.10259366	0.00102594			0	0	0
Sulfur	0.01198847	0.00011988		1.15274E-05	1.15274E-05	0.00011527	0.000391931
			sum	0.003331412	0.012495677	0.10625937	0.349636888
				Theoretical air supply		0.45591	kg/kg of fuel

Solar assisted heat generated in the furnace is determining through the thermal impact that every waste component has on the process. See Table 5.14. In this calculation process the thermal impact of every individual process, multiplied by its flow, is added up to get a summarized heat generation. The processes are combustion, vaporization and heating of inert compounds. This summarized heat generation in can be compared to the power input from the waste flow to get the incineration grate efficiency, η_{grate}.

Table5. 14 Solar assisted heat generation results of combustion calculation

Column1	Flow [kg/s]	Thermal contribution [kJ/kg]	Thermal Impact [KJ/s]
Water content	0.6274	-2591.4	-1625.76
Ashes (inert)	0.0244	-69.17	-1.68495
Reaching comb.temp	6.6400	-616.63	-4094.42
Carbon	1.0153	33913	34430.41
Hydrogen	0.1453	142770	20746.77
Nitrogen	0.0326	-945.49	-30.84472
Sulfur	0.0038	10467	39.68040
Excess oxygen	0.8570	-836.29	-716.7005
inert N2	0.340	-945.49	-321.0695
Average Thermal power output [kw]			48426.372
Average Thermal power output [Mw]			48.426372

To demonstrate different possible furnace designs that would lead to different flue gas temperature distributions, a few scenarios of initial heat exchange temperatures have been set up. See Table 5.15. The range of possible temperatures is 250-1400^{0}C, where the lower limit is set by emission regulations and highest limit is the highest theoretical combustion temperature. A portion from the initial temperatures, the temperatures are pre-determined.

The majority of the heat exchange to the steam cycle in the boiler. Then this it enters the flue gas treatment, where the heat between 130-155^{0}C is consider filter losses. Before the gases are release through the chimney, the heat between 130-70^{0}C is used to preheat the combustion air. Since this portion improves the combustion it is not considered a loss.

Table 5.15 Heat exchange scenarios From T=250^{0}C:the minimum allowed furnace temp T= 1400^{0}C: the highest theoretical temperature.

Flue Gases	h[160]-case		h[168]case		h: From to Heat gen		h[300]-case	
h Flue gas	505.527	kJ/kg	592.385	kJ/kg	1000.3299	kJ/kg	1763.48	kJ/kg
p Flue gas	11.32	MW	13.5458	MW	48.4263	MW	170.90	MW
Boiler [ΔT] ηboiler	[160-155^{0}C]	η = 80%	[168-155^{0}C]	ηb = 82%	[T spec-155^{0}C]	η = 86%	[1400-155^{0}C]	η = 94.1%
h Boiler	429.69795	kJ/kg	503.52725	kJ/kg	860.830415	kJ/kg	1593.438	kJ/kg
p Boiler	9.622	MW	11.51393	MW	41.162355	MW	154.42	MW
Filter losses	[155-150^{0}C]		[155-130^{0}C]		[155-130^{0}C]		[155-130^{0}C]	
	27.69	kJ/kg	27.69	kJ/kg	27.69	kJ/kg	28.89	kJ/kg
	2.65	MW	2.65	MW	2.65	MW	2.65	MW
Air pre-heat	[130-70^{0}C]		[130-70^{0}C]		[130-70^{0}C]		[130-70^{0}C]	
	7.5101	kJ/kg	7.5101		7.5101		65.5101	kJ/kg
Regained preheat	0.72738	MW	0.7274	MW	0.72738	MW	6.7274	MW
Exhaust	0.84957	MW	0.8496	MW	0.84957	MW	7.37	MW
Total p Boiler	6.84981	MW	8.7417	MW	38.39016		160.73	MW

5.9. 2. Solar assisted CYCLEPAD display results

By using the above data the result is display in CYCLEPAD in the following two ways.

1. The numerical value of reversible cogeneration Rankine cycle result.

Display the diagram and cycle properties results in Figure5.10. The cycle is Rankine heat engine.

Because of reversible cycle the exergy power output equals of power output of reversible cycle.

$$\Delta\Psi = \sum(H - TOS)e - (H - TOS)i = \sum(He - Hi) = 38.305\ KW \quad (5.11)$$

Power output for reversible cycle = 38,497 KW ~38.5 MW

Power input for reversible cycle = -191.7 KW~0.1917 MW

Net power output for reversible cycle = 38,305 KW = 38.3 MW

Carnot efficiency for reversible cycle = 38.38%

Thermal efficiency for reversible cycle = 27.99 %

Q-dot in boiler for reversible cycle = 136,868 KW

Q-dot out in condenser for reversible cycle = -98,562 KW

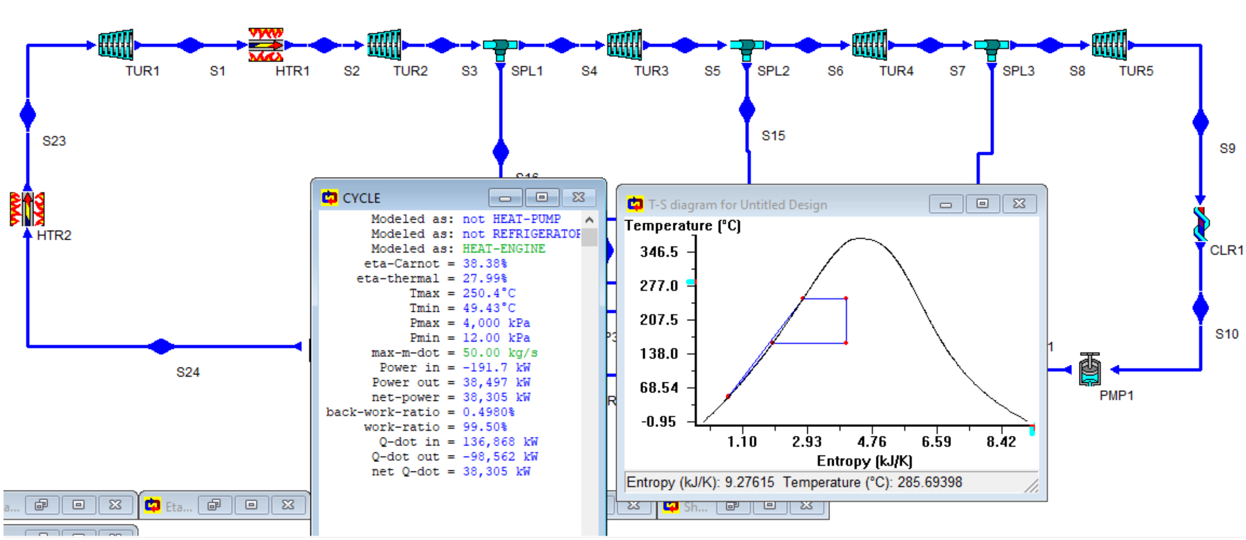


Figure5. 10 display result in CYCLPAD

2. Discussion by using sensitive diagrams.

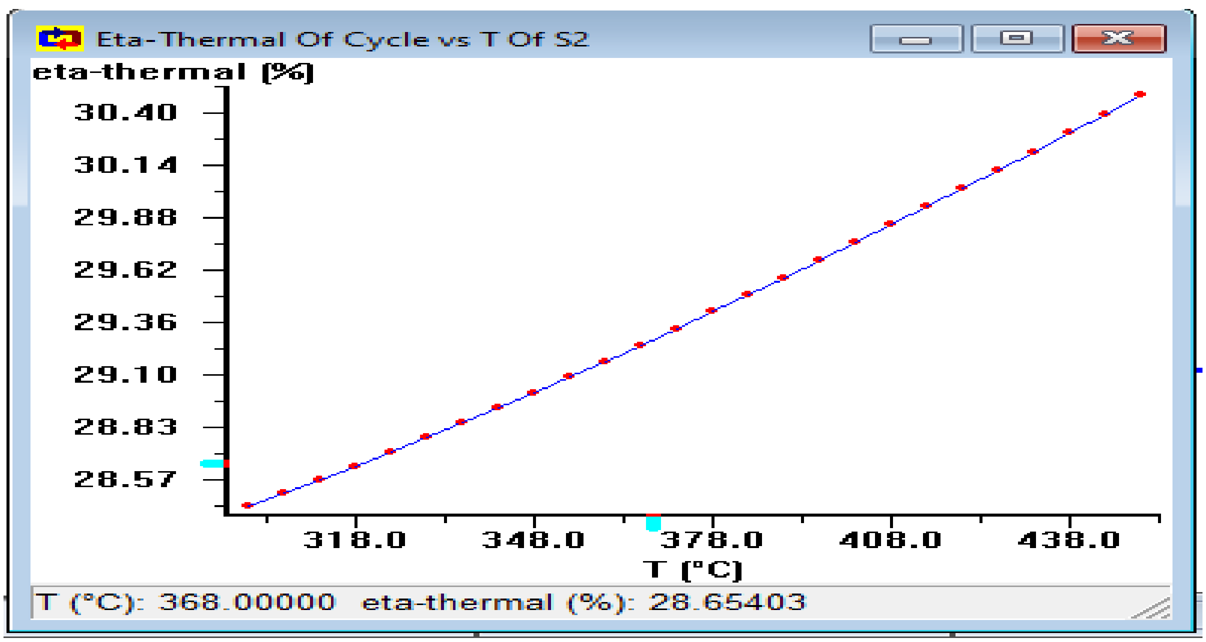


Figure5. 11 thermal efficincy vs T

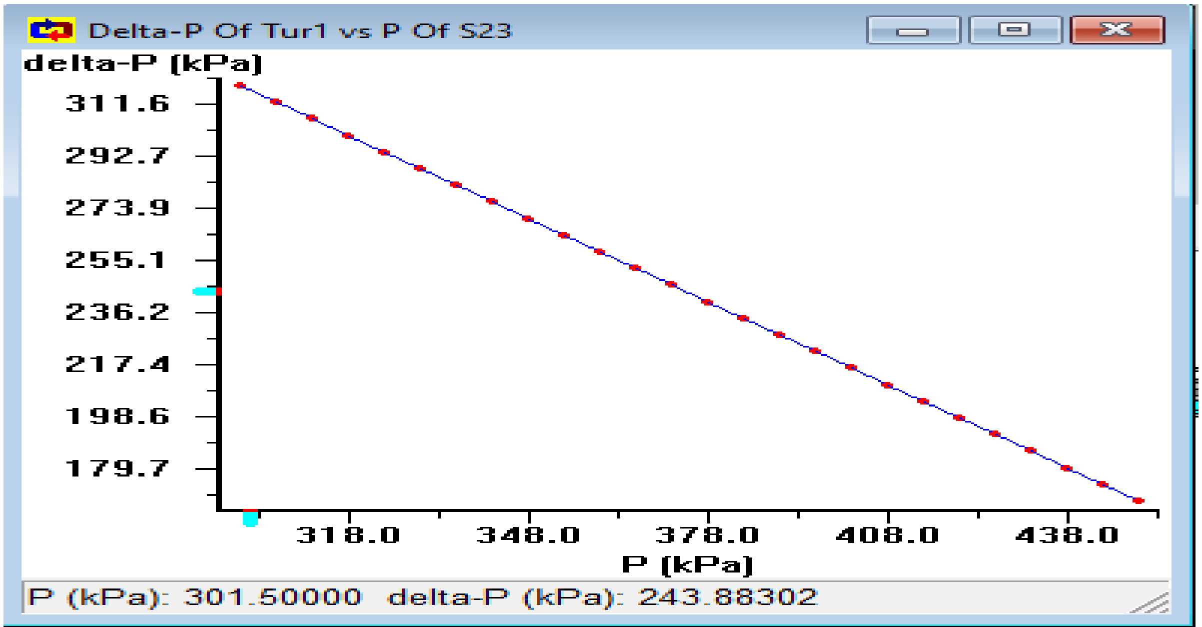


Figure5. 12 delta-p of Hp turbine vs p

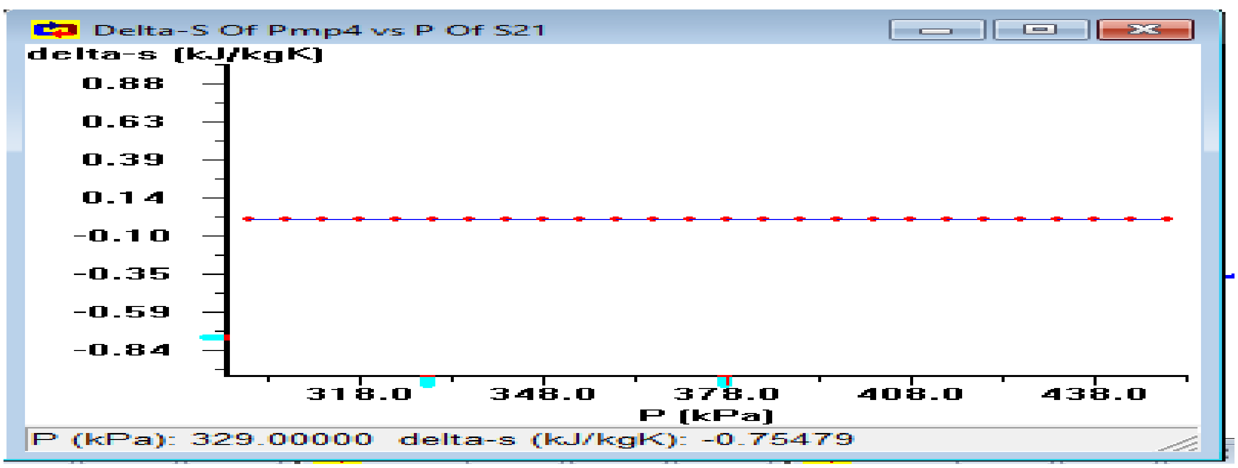


Figure5. 13 delta-s-of pump vs pressure

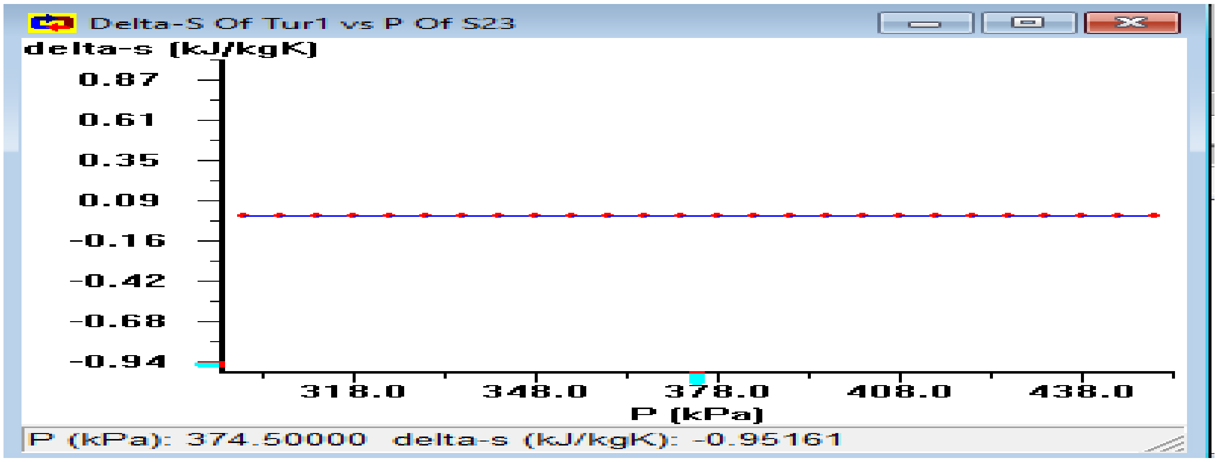


Figure5. 14 delta -s of Turbine vs p

Comments: from the sensitivity diagram in Figure 5.11 of cycle efficiency vs temperature. It is seen that the higher the temperature, the higher the cycle efficiency. The temperature is limited, due to metallurgical considerations. Presently, the maximum operating superheat temperature is 620^{0}C, from the sensitivity diagram in Figure 5.12 of the delta-p of high pressure turbine vs pressure. It is seen that the higher delta-p the lower pressure. The pressure is limited duet to pump capacity and metallurgical considerations, from the sensitivity diagram in Figure 5.13 and 5.14 of delta-s of pump and delta-s of Turbine remain the same, due to reversible cycle.

Because of irreversible the cycle exergy power output not equal to power output of cycle. The average temperature in Adama T_o =25^{0}C (298k).

$$\Delta\Psi = \sum(H - TOS)e - (H - TOS)i = \sum(He - Hi) - T_o(Se-Si) \qquad (5.12)$$

Net exergy power irreversible ($\Delta\Psi_{net}$) =28485.67 KW

Power output for irreversible cycle = 33,467 KW ~33.467MW

Power input for irreversible cycle = -225.7 KW~0.2257 MW

Net power output for irreversible cycle = 33,241 KW = 33.241 MW

Carnot efficiency for irreversible cycle = 38.38%

Thermal efficiency for irreversible cycle = 25.75%

Q-dot in boiler for irreversible cycle = 134,771 KW

Q-dot out in condenser for irreversible cycle = -102,760 KW

Net Q-dot for irreversible cycle=33,241 KW

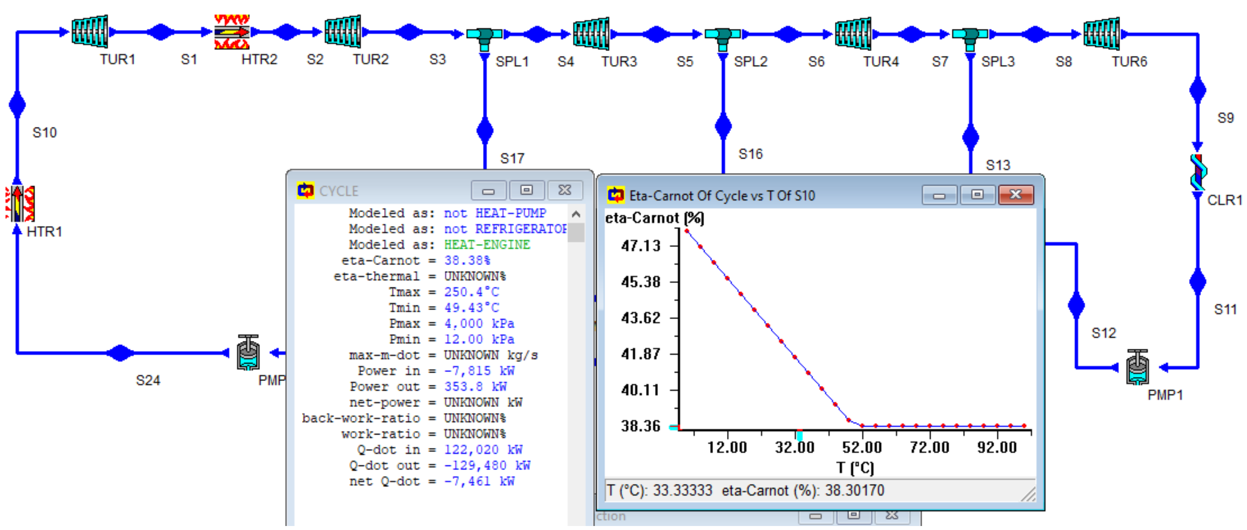


Figure5. 15 Result of steam cycle solar assisted

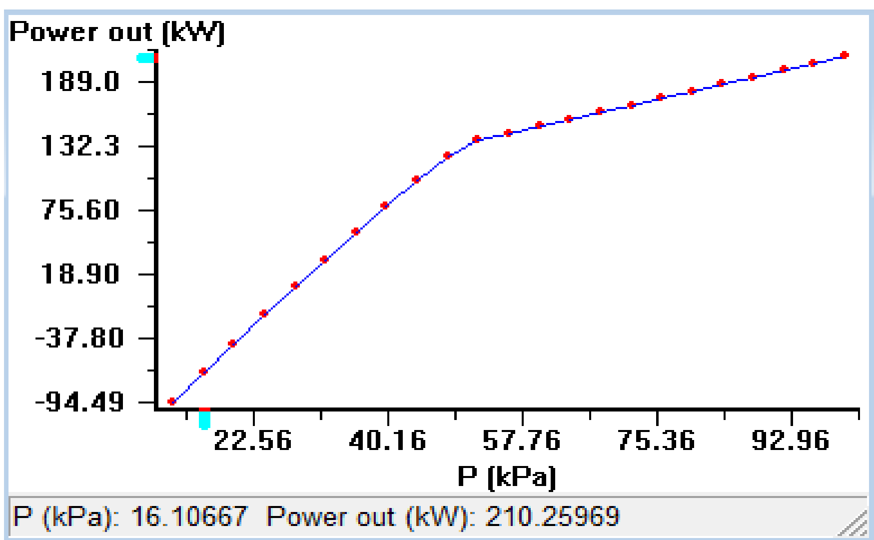


Figure5. 16 power out vs pressure

From Figure 5.16 see that at the first stage power output and pressure is simultaneously increase but the last stage pressure have limits and power output also limited because of pressure.

5.9.3. Solar assisted result cross comparison by MECH IN EXCEL, and PYTHON

The reversible and irreversible cycle result also displays in MECH IN EXCEL, and PYTHON were displayed results in Table 5.16, Table 5.17, and Table 5.18 the full calculation and python code displayed in appendix 1. This calculation done based on Rankine cycle principle which means analyzed on Ideal and Real Rankine cycle.

Table5. 16 Cycle result in MECH IN EXCEL

Steam cycle in Mech in excel	Work	value	Uint
work done in turbine one 1s	w_t1s	153.125146	KJ/kg
work done in turbine one 1a	w_t1a	130.156374	KJ/kg
efficiency of turbine and pump	Effi	0.85	Value
work done in first stage turbine 1s	w_st1s	185.249418	KJ/kg
work done in first stage turbine 1a	w_st1a	157.462005	KJ/kg
work done in first stage turbine 2s	w_st2s	168.479813	KJ/kg
work done in first stage turbine 2a	w_st2a	143.207841	KJ/kg
work done in first stage turbine 3s	w_st3s	115.025625	KJ/kg
work done in first stage turbine 3a	w_st3a	97.7717813	KJ/kg
work done in first stage turbine 4s	w_st4s	205.915429	KJ/kg
work done in first stage turbine 4a	w_st4a	175.028114	KJ/kg
work required for first pump 1s	w_pt1s	0.02112088	KJ/kg
work required for first pump 1a	w_pt1a	0.02484809	KJ/kg
work required for second pump 2s	w_pt2s	0.07802298	KJ/kg
work required for second pump 2a	w_pt2a	0.09179174	KJ/kg
work required for third pump 3s	w_pt3s	0.18509055	KJ/kg
work required for third pump 3a	w_pt3a	0.21775359	KJ/kg
work required for fourth pump 4s	w_pt4s	3.86669862	KJ/kg
work required for fourth pump 4a	w_pt4a	4.5490572	KJ/kg
work required total	w_rtotal	4.88345062	KJ/kg
work net	w_net	698.742666	KJ/kg
work required for pump total ideal	w_rnet ideal	4.88345062	KJ/kg
work total ideal	w_net ideal	827.795431	KJ/kg
work done net	w_total	703.626116	KJ/kg
work net ideal	w_total net ideal	822.911981	KJ/kg
mass flow rate	dm_dt	47.25	kg/s
power out put ideal	power ideal	38882.5911	Kw
power out put	Power	33015.591	KW
power out put	Power	33.015591	MW

Result of reversible (ideal) steam cycle which is isentropic process, in MECH IN EXCEL.

Net exergy power reversible ($\Delta\Psi_{net}$) =37,740.4606 KW

Power output for reversible cycle = 37971.20 KW ~37.971MW

Power input for reversible cycle = -230.74 KW~0.230 MW

Net power output for reversible cycle = 37,740 KW = 37.740 MW

Result of irreversible (actual) steam cycle which is isentropic process, in MECH IN EXCEL.

Net exergy power irreversible ($\Delta\Psi_{net}$) =27485.67 KW

Power output for irreversible cycle = 32,275 KW =32.275MW

Power input for irreversible cycle = -230.74 KW= -0.2307 4MW

Net power output for irreversible cycle = 32,044 KW = 32.044 MW

As Table 5.16 shows the result that gets in CYCLEPAD is correct because the difference between CYCLEPAD and MECH IN EXCEL are less than one. Also when compere the exergy power output it is similar 98 % which is this also shows that the calculation done by CY Table

5.17 Solar assisted steam cycle result in PYTHON

Reversible steam cycle in PYTHON	Value	Unit
Total work done of the turbine in ideal	811.27	KJ/kg
Total work required for pump in ideal	4.12	KJ/kg
Network output of the plant in ideal	807.15	KJ/kg
Power output of the plant in ideal	38137.99	KW
Power output of the plant in ideal	38.14	MW

Net exergy power reversible ($\Delta\Psi_{net}$) =38,137.4606 KW

Power output for reversible cycle = 38,332.5075KW =38.332MW

Power input for reversible cycle = -194.67 KW=0.19467 MW

Net power output for reversible cycle = 38137.4606 KW = 38.137 MW

Table 5.18 Solar assisted steam cycle result in PYTHON

Irreversible steam cycle in PYTHON	Value	Unit
Total work done of the turbine	689.58	KJ/Kg
Total work required for pump	4.12	KJ/Kg
Network output of the plant	684.74	KJ/Kg
Thermal efficiency for cycle	55.22	%
power output of the plant	32353.75	KJ/Kg
Power output of the plant in MW	32.353	MW

Net exergy power irreversible ($\Delta\Psi_{net}$) =28985.67 KW =28.985MW

Power output for irreversible cycle = 32,582.655 KW =32.275MW

Power input for irreversible cycle = -194.67 KW= -0.19467MW

Net power output for irreversible cycle = 32,353.75 KW = 32.353 MW

As Table 5.11, and Table 5.12 shows the result that gets in CYCLEPAD is correct because the difference between CYCLEPAD, MECH IN EXCEL, and PYTHON are less than ten. Also when compere the exergy power output it is similar 95 % which is this also shows that the calculation done by CYCLEPAD is correct.

The above three assumption required real measurement, but in this project doing real measurement is impossible, because this type of measurement need investment capital and time of building bunker, not only this the equipment of measurement also required. As this project made of master level, I can’t afford the above measurement. Also the aim of this project to show how much energy potential can have from solid waste material that disposed in landfill of Adama twon

CHAPTER SIX
Economic and Financial Analysis

6.1. Introduction to separate Methodologies

When dealing the economic viability of the Adama waste-to-energy facility, on this feasibility study relies on two main analytical methodologies, namely an economic analysis and a financial analysis.

Financial Analysis considers only the small portion of financial aspects of the project itself to determine whether it is financially viable on a strictly commercial and standalone basis. The Economic Analysis considers large portion of benefits accruing to an economy; according to the World Bank's "Handbook for Economic Analysis of investment Operations", the main goal of an Economic Analysis is to help design and select projects that contribute to the welfare of a country.

In the Economic Analysis this Feasibility Study considered two additional benefits accruing to the Ethiopian economy from the facility:

1. Financial savings resulting from the minimum costs of operating landfill sites in Adama as waste is converted to the facility for change to energy.
2. Financial savings out coming from the replacement of more expensive diesel-generated energy with that of the Adama waste to Energy Facility. Such saving have been calculated on an annual basis over a 20-year operating period.

6.2.Method used for alternative (clean development Mechanism)

Together the Financial and Economic analyses of the Feasibility investigation a separate ways is created, considering the impact that the inclusion of Certified Emission Reduction credits (CERs) of the clean development Mechanism has on the financial results. CERs should be available to Adama waste-to-energy plant on the basis that landfill waste is being disposed of in a much cleaner way and the resultant clean energy created will replace more harmful fossil fuel-generated energy.

6.3. Determination of performance measures

In this feasibility study three different measures used to assessing the financial viability of the Adama waste-to-Energy.

NPV (Net Present Value) –the difference between the present value of the project's cash inflows and outflows, a largely used methodology for determining any investment project's viability. I have evaluated the NPV using three different discount rates -8%, 10% (Base Case) and 12%.

IRR (Internal Rate of Return)-the discount rate which makes the present value of the project's cash flows equal to zero. The higher IRR, the more attractive the waste-to-energy project

Benefit Cost Ratio ("B/C Ratio") –the project's total discounted benefits divided by the total discounted costs. A B/C Ratio greater than 1 means a project has greater benefits than costs.

6.4. Adama city waste-to-energy (WTE) economic and financial analyses

The purpose of the Economic Analysis is to compare from a macroeconomic standpoint the benefits of the project with the costs it incurs, as is customary in any cost-benefit determination. The standard of evaluation for costs and benefits is a monetary quantification. To the greatest possible extent, the project impacts are evaluated in terms of economic market prices. Calculations have been made for the years 2013 to 2042 (i.e., the years in which the waste –to-energy plant will have undergone its average expected life). This Feasibility study recommends that study recommends that with a major overhaul at year of thirty the plant may have an additional twenty years of operational life. This gives the plant a total residual value of over 40% by its anticipated end of life, but in this feasibility study considered a residual value of 15%, in line with different literature reviews recommendation. The residual value presents a significant potential value to municipal city of Adama and EEPCo. However, as stated, all present calculations have been undertaken with the expectations that the plant will have a lifetime of only thirty years.

The waste-to-energy plant is different from hydro dominated power plant, which is takes garbage as an input and then recycles and disposes of it in the process of creating hydrogen rich-syngas that is used as fuel for its gas engines. The capital expenditure for both the garbage processing and gasification portion of the facility produces revenue in different ways. Adama waste-to-energy facility is an amalgamation of three facilities in one, a recycling facility, a sustainable landfill alternative, and a means of power generation, each of which has its own respective economic feasibility. This feasibility study addresses the macro-economic value of all three facility components and their respective impacts on the Ethiopian economy.

Recycling: at the beginning of the facility stores, shreds, and dries all incoming waste. The segregates and identifies significant amount of ferrous metal, non-ferrous metal (e.g. aluminum cans), glass and other inert and non-inert materials. The facility will generate a meaning full amount of income by selling metals to companies within Ethiopia at a discounted price of ETB 7 per kilogram of discarded metal. As we know Ethiopia does not have large-scale steel manufacturing and relies largely upon recycling and imported steel.

Garbage disposal: in this feasibility study I assume that the economic value of the Adama waste-to-Energy plant can save over 40% of the cost of managing landfills. For the purpose of the study, 15% saving with a 2% appreciation has been employed for the purposes of this analysis.

Electricity generation: Adama waste-to-energy plant has been estimated to produce an annual energy output of 118,733.04 KWh, which will be sold at a weighted average tariff of USD 6cents (1.05birr) and increase over time in accordance with EEPCo's planned increase of 10% every five years. While EEPCo advises that sales tariffs are as low as 0.35USD/KWh, a rate of o0.06 USD/KWh applies to new generation projects, as shown in figure 6.1 the cost tariff increase in five year interval.

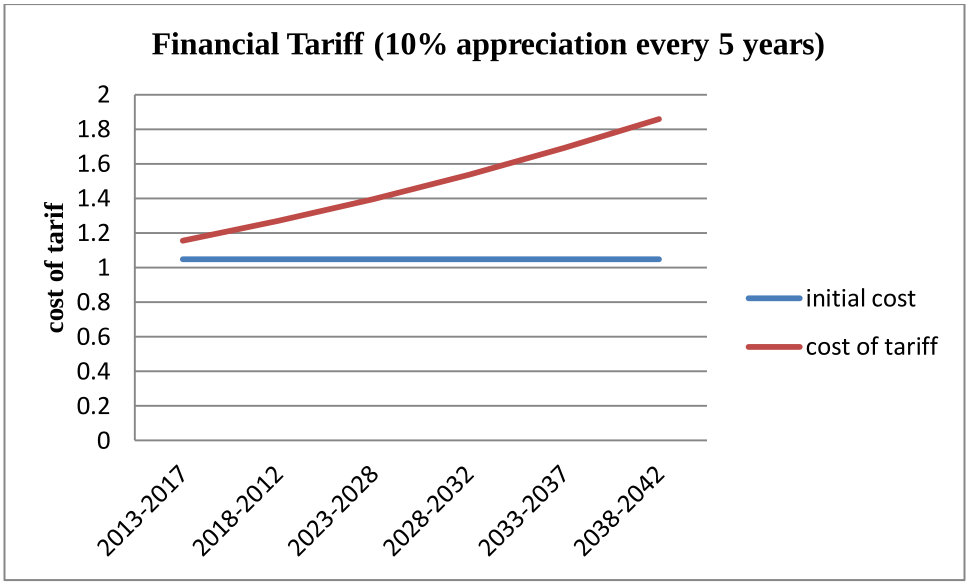


Figure 6. 1 Cost tariff increase in five year interval

For this purpose, the economic costs of the project are compared to its economic benefits. Both costs and benefits are set up as cash flows over the economic lifetime of the plant, including the constructive period and the operation period, let's ignore the difficulty and assuming the plant is commissioned in 2020 and that it has an economic lifetime of thirty years. A discount rate of 10% is used for the base case economic evaluation.

6.5. Indirect benefits from waste-to-energy of Adama power plant

The most indirect benefits that have not been mentioned in this feasibility study, however, there are to be considered, are the following.

- ✓ The fact that the waste-to-energy facility reduce the absolute consumption of diesel fuel that extract from fossil fuel, which is relatively expensive when compere of two fuel.
- ✓ The power generation will become more diversified
- ✓ The imported of diesel fuel will become decline
- ✓ The project supports the energy policy objectives of the Government of Ethiopia.

6.6. WTE Economic analysis based on cost of unserved energy (CUE)

As illustrate in the above, based on the recommendation from EEPCo the in this feasibility study examined the study of, "Electricity Tariff study, Energy II project" by Scott Wilson Piesold (in association with power planning Associates) in order to preparing this document. The study calculates the cost of unserved energy (CUE) to model economic benefits for Ethiopia. In order to understand the economic impact of any given energy project, it is necessary to consider the consequences were that power not to be generated. CUE in Ethiopia is comprised of two parts

- The cost of announced and foreseeable outages due to insufficient power generation and delivery capacity.
- The cost of unreliability, i.e., the consequences of sudden and unplanned power outages.

Combinations of two basic estimation techniques are used:

- Calculating the foregone consumer surplus, this is related to the consumer's willingness to pay.
- Calculating the foregone production or other economic output that would have occurred had the electricity been available.

This Economic Analysis recognizes that often there is a non-linear relationship between the cost associated with outages and their duration. For example, a paper mill or a textile mill may have an outage that lasts only minutes but may result in production losses around 1 hour while processes are restored.

6.7. Planned outages

This Analysis assumes that the cost of a planned outage in the residential sector is equivalent to the foregone consumer surplus, which is in turn the amount that the consumer would have been willing to pay for each unit of electricity as consumption increases. This can be based on the customer's willingness to pay.

In the commercial sector, we assume that the customers who would potentially be most affected by planned outages are most likely to have an alternate supply. For these customers the CUE equates to the cost of the alternate supply. The cost is typically higher than the cost of grid-supplied electricity.

6.8. Unplanned outages

The Analysis assumes that unplanned outages are more costly per unit energy lost than planned outages. The example of the paper or textile mill supports this argument. For the residential sector the analysis adopts a consumer surplus approach similar to that for planned outages, we note, however, that the average willingness to pay underestimates the cost of planned outages. The cost of electricity substitutes such as candles or kerosene can be taken.

6.9. Adama waste-to-energy investment calculations

6.9.1. Investment cost

The investment cost for the project has been discussed with several Rappi energy project and literature review. The estimated investment cost is around **149.52**[MUSD], the partial costs are displayed in Table 6.2.

Table6. 1 Cost of substation and Transmission line

Item	Total price (USD)	F/C (USD)	Local portion (USD)
Substation Cost	3,670,000.00	3,303,000.00	367,000.00
Transmission Line Cost	720,000.00	648,000.00	72,000.00
Total Cost	4,390,000.00	3,951,000.00	439,000.00
Engineering and Administration 5%	219,500	197,550.00	21,950.00
Total project Cost	4,609,500.00	4,148,550.00	460,950.00
Physical Contingency (5%)	230,475.00	207,427.50	23,047.50
Price Contingency (10%)	460,950.00	414,855	46,095.00
Grand Total project Cost (USD)	5,300,925.00	4,770,832.50	530,092.50
Grand Total Project Cost (Birr)@1USD=29 Birr	153,726,825.00	138,354,142.50	15,372,682.50

Table6. 2 The total investment cost

Type	Investment cost [MUSD]
Funnel, Furnace, DeNOx, Steam Boiler *	85.00
Bunker, "House"*	20.00
steam Turbine, Generator, DH Condensers**	10.00
Flue gas cleaning system ***	13.11
Cooling Tower ****	3.00
Unforeseen costs of 10% of total investment	13.11
Total	**144.22**
Grand Total project cost (USD)	**5.30**
Over all the investment cost (USD)	**149.52**
* Anderz Wahlstrom. VonRoll	

**Micheal Mazur siemes AB	
***Rolf Hunt, Alstom	
**** simon Jansson, Ragn-sells Miljokonsult AB	

Comments

The total investment cost is based on four different sources which can lead to a greater uncertainty then if only one source was used. But a project of this size involves several entrepreneurs that will lead to an uncertainty in the first investment cost estimation.

6.10. Adama waste-to-energy yearly cash flow

Yearly income from sales of electricity is one result from the excel calculation. The resulting yearly cash flow is shown in Table 6.3 below. The individual components can be found in Appendix II. Two scenarios are tested for the cash flow and payback time. The scenarios are without taxes. The payback time for this project is 31.45 without taxes.

Table6. 3 Cash Flow and Payback time, no taxes

Type. Without taxes	[MUSD]
Investment	149.22
Incomes	48.35
Salaries	-0.42
Chemicals	-0.97
Landfill	-7.02
Maintenance	-7.21
Support fuel	-1.17
Cash flow per year	31.56

6.10.1. Payback time

The different scenarios impact on the payback time is displayed in Table 6.4.

Table6. 4 Payback time scenarios

Scenario	payback time [years]
Original without tax	31.45
10 % higher costs without tax	31.93
10 % higher investment without tax	32.14
10 % less profit without tax	33.47

6.10.2. Net present value, NPV

The interest and discount rate are calculated in NPV included which leads to a longer time before the investment has paid off then the simpler method, payback time. The different variations of investment calculations are displayed in Table 6.5, Table 6.6, and Table 6.7. The time the investment requires to be profitable varies between 7 and 10.5 years depending on the rate scenario without taxes included. The accumulated profit result varies between 59 USD and 150USD depending on scenario. The internal rate of return (IRR) for the three different interest scenarios without included taxes are displayed as the discount rate that gives zero accumulated profit after 20 years. The IRR varies between 19.6% and 17.6% without.

Table6. 5 Accumulated profit in Project lifespan, 4% interest rate

Accumulated profit		without taxes
interest rate	Discount rate	[MUSD]
4%	8%	150.41
4%	10%	109.86
4%	12%	77.49
4%	19.63%	0.00

Table6. 6 Accumulated profit in project lifespan, 6% interest rate

Accumulated profit		Without taxes
Interest rate	Discount rate	[MUSD]
6%	8%	141.26
6%	10%	101.15
6%	12%	69.17
6%	18.64%	0.00

Table6. 7 Accumulated profit in project lifespan, 8% interest rate

Accumulated profit		without taxes
Interest rate	Discount rate	M[USD]
8%	8%	130.99
8%	10%	91.39
8%	12%	59.90
8%	17.60%	0.00

Comments

As we see all the different discount and interest rate scenarios without taxes lead to a result that is feasible and gives the investor an opportunity for a higher discount rate. With the pre-determined discount and interest scenarios the profit can be lowered by reduced sale price of electricity.

6.10.3. Internal rate of return

The different scenarios impact on the internal rate of return is displayed in Table 6.8 below. The highest IRR is 19.3 % and the lowest 9.54 %.

Table6. 8 Internal rate of return, all scenarios

10 % hgher costs	**without Tax**
Interest rate [%]	IRR [%]
4	19.32
6	18.33
8	17.29
10 % higher investment	without Tax
Interest rate [%]	IRR [%]
4	16.96
6	15.94
8	14.83
10 % less profit	without Tax
Interest rate [%]	IRR [%]
4	15.96
6	14.9
8	13.76

CHAPTER SEVEN
CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

This study with all of its conditions shows that the best solution for Adama is 32.1 MW WTE plant with specifications according to Table 7.1.

Table7. 1 Finalized system design

Finalized system design		
	Description	Explanation
Location	Around the exit of Adama	Connected to waste logistics and large site
Bunker	$14{,}400m^3$	5.71 tones/h, 3 days of storage
Incineration	2 lines moving grate furnaces	Von Roll system Operation safety and Thermal irregularities
steam boiler	250.4^0C, 4000kpa, 2 lines , 22.5 MW each	Investment and maintenance costs, operation safety
Turbine and generator	16MW and 27MW	Siemens suggestion: SST-300
Electrical output	118.733 GWh	
Thermal output	264.45 GWh	
Flue gas treatment	semi dry, SNCR-DeNOx system	Alstom Semi dry suggestion: NID™ system
Chimney height	77m	Swedish standard for similar terrain
Cooling	GEA air cool condenser 44 MW cooling capacity	Designed to handle thermal spikes during summer

7.2. Potential for this WTE solution in Adama

The results of this study show that the implementation of a WTE plant in the Adama energy system is both economically and environmentally feasible, given the current conditions. The general opinion is very positive among the Adama government officials and experts, but the difficulty in funding the investment has also been pointed out.

Initiating a waste to energy project in Adama has been discussed for a number of years now, but still no project has managed to become reality. Several other energy projects have been in the final stages of discussion during the time of this study, but the waste situation seems to have a lower priority.

Politically, the public opinion on waste incineration is still negative due to lack of knowledge. What needs to be pointed out is that the situation is different since the arrival of a Cambridge industry and the initiated cooperation between Adama.

Environmentally, the implementation of this project would make a significant improvement to greenhouse gas emissions compared to the current situation. The fossil CO_2 released from waste incineration is very low compared to the combination of landfill methane and CHP CO_2 emissions. Toxin emissions are often seen as the negative part of waste incineration. This project, with the toxin emissions compared to a landfill.

In summary, the feasibility of this project is clear with only a few obstacles that need to be considered.

- Gaining international funding for the project
- Focus on reliability and experience in the choice of consultants, suppliers and contractors.
- Education of permanents staff or the plant, operation and waste accumulation.
- Connection, expansion and renovation of the district heating grid
- Population spending power with the increasing heat prices.

7.3. Discussion

7.3.1. Potential sources of uncertainty

The data used to do this study is taken from more than 10 different sources with varying scientific level. Some values are mathematical and proven, some are qualified estimations and some have been obtained through empirical studies. In the study we have viewed all our sources critically and verified that all the unit conversions have been done correctly. However, it is still difficult to claim that the results are entirely reliable with this wide spread of sources. Here is a list of thoughts that have emerged during the study.

7.3.2. Waste composition, heat generation and flue gas

First of all, the waste data needs to be addressed. The data used in the study is not going to accurately apply for the Adama area, but all experts interviewed about the matter have assured us the current waste composition is ”good enough” estimation. Another source of uncertainty is the residues fraction of the waste. As previously mentioned this has been compensated for by spreading it over the other components. This is likely to result in a waste composition with higher combustible and moisture content than the real case but we have found no better way. The result of this is a higher calorific value, and therefore a larger heat generation. The heat generation process also involves more chemical reactions than the ones included. The others, however, are rarely mentioned in practical studies and have therefore been disregarded.

The other source of uncertainty that has great impact is the actual combustion/flue gas temperature. The theoretical temperature can easily be calculated, but a more realistic temperature is very difficult to estimate without expertise. Therefore several cases have been presented in the study to somehow capture the span of possible energy levels.

For the flue gas composition, like the heat generation, only the amounts of the important energy carrying components have been calculated.

7.3.3. Steam cycle model

First of all, the model has several defined values that could have been made dynamic with a larger project timeframe. Such values are the number of turbine and the superheated steam data, set at 250^0C and 4000kpa, which sets limits to the potential output.

Secondly, this steam cycle is considered as a simplified thermodynamically ideal system with no thermal losses in pips, tanks and condensers. If desired, this could be compensated by adding an extra steam cycle loss. Also, apart from assuring steam and water flows are always saturated, no time has been spent on flow turbulence and the corrosion it may cause.

Thirdly, instead of estimating continuous mathematical function which could be optimized with high accuracy, the model runs a chosen set of discrete values against each other. This means that the model is unlikely to deliver the exact optimal value, but recalculating with new value intervals will get you close enough.

7.3.4. Environmental Comparison

In the environmental comparison the WTE emissions have been done theoretically. The gas turbine emissions are estimated using data from the US Government, while landfill emissions are estimated using a model done by IPCC. That is not ideal, but it gives a good idea of the way the two cases compare.

7.4. Recommendations

In order to get an accurate result you need accurate input values. For this model to deliver the most truthful result possible some further studies need to be done. The most significant areas have been narrowed down to the following.

- Waste
    - Detailed waste composition
    - Future waste accumulation
    - Potential for sorting and recycling
- Future development of economical parameters specific for Adama
    - Inflation
    - Consumption goods prices
    - International economical relations

REFERENCE

[1]. Swedish Environmental Protection Agency. *ALLMANNA RAD 90.3*. [online] [Citat:den 1902 2012.] http://www.naturvardsverket.se/Documents/allmrad/ar_90_3. Pdf.

[2]. Us Environmental Protection Agency.[online]

http://www.statistica.md/newsview.php?l=ro&idc=1688&id=3640.

[3]. Engineering toolbox.[online] http://www.engineeringtoolbox.com/specific-heat-metals-d_152html.

[4]. ANRE. ANRE.*ANRE*.[online] 02 2012. http://anre.md/rate/index.php?vers=l&sm=11.

[5]. Change, International Governmental Panel on Climate. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. [online] 2006.[Citat:den 06 02 2012.] http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

[6]. Alstom. Alstom NID system. Alstom.[online]

http://www. alstom.com/power/resources/brochure/nid-flue-gas-desulphurization.

[7]. Siemens. Siemens. [online] http://www,energy.siemens.com/fi/pool/hq/power-generation/steam-turbines/SST-300/downloads/SST-300_en. Pdf.

[8]. GEA. GEA.[online]

http://www.geaict.com/opencms/export/sites/default/galleries/gpc_gallery/air_cool_condensers. Pdf.

[9]. Regeingen. Swedish Government.[online] Jan 2012.

http://www.regeringen.se/sb/d/5472/a/43789.

[10]. Chisinau, Autosalubritate- Waste Management dept. Autosalubritate –Explained. [online]

http://www.chisinau.md/pageview.php?l=ro&idc=473.

[11]. Statistics, National Bureau of. Statistical Yearbook "Chisinau in Figures".[online] 2011.[Citat: den 18 01 2012.]

http://www.statistica.md/public/files/publicatii_electronice/chisnau/Anuar_Chisinau_ed2011. Pdf.

[12]. AllMOLDOVA.com. AllMoldova.com.[online][Citat:den 18 01 2010.]

http://www.allmoldova.com/en/moldova/info/climate.html.

[13]. Wtert.wtert.[online]wtert.

http://www.wtert.eu/global/images/doki/components_and_operation_of_solid_particle_removers
. Pdf.

[14]. Wikimapia-Centrala Termica Est. [online] [Citat:den 07 02 2012.]

http://wikimapia.org/7914434/ro/Centrala-Termic%C4%83-de-Est-1992-1999-nu-func%C5%A3ioneaz%83.

[15]. price, H., A parabolic Trough Solar power plant simulation Model, in International solar Energy Conference Hawaii Island. 2003, National Renewable Energy Laboratory:Hawaii. p.5.

[16]. Cambridge industries energy and Ethiopian Electric Power Cooperation, 2007

[17]. Aron Asgedom, 2017. Research energy recovery possibilities from municipal solid waste in Addis Abeba, Ethiopia.

[18]. M. coffey, A. Coad, "Collection of Municipal solid waste in Developing Countries", United Nations Human settlements program (UN-HABITAT) Nairobi, kenya. 2010.

[19]. Babcock and wilcox volund A/S. 2012.21' Century advanced concept for waste-fired power plants.

[20]. Mengist Hailemariam, 2014 Solid Waste Management in Adama, Ethiopia: Aspects and challenges.

[21]. Global waste management market report 2004, Research and markets, Dublin, Ireland.

[22]. The Danish Environmental protection Agency, waste statistics 2004, April 2005, www.mst.dk

[23]. ARTELIA,(2014). Solid waste management project- strategic and Technical studies and works supervision, Addis Abeba city Government- Ethio-french cooperation, Addis Abeba.

[24]. Mesfin Tilaye' and Melne pleter van Dijk, 5,2014. Sustainable solid waste collection in Addis Abeba: the Users' perspective.

[25]. Sibley J, Hes D. Martin p (2003) A triple helix approach inter disciplinary approach to research in to sustainability in outer suburban housing estates. Methodologies in housing

research. stockholm

[26]. Tilaye M, van Dijk MP (2014) private sector participation in solid waste collection in Addis Abeba (Ethiopia) by involving micro-enterprises. Waste Mange res 32: 79-87.

[27]. Van Dijk MP, Tilaye M (2013) Micro-privatization of solid waste collection service, the case of Addis Abeba city. In Water lines 32: 154-162.

[28]. Johansson , T.B. and L. Burnham, Renewable energy: sources for fuels and electricity, F.M., Low pressure boilers. 1970, Chicago: American Technical Society.

[29]. kaltschmitt, M., W.Streicher, and A. Wiese, Renewable energy: technology, economics, and environment. 2007, Berlin; New York: Springer.

[30]. Technology Characterization Solar parabolic Trough. [cited 2009 27th July]; Available from:

[31]. Alvarez, Henrik. Energiteknik. S.l.:studentlitteratur, 2006.

[32]. Ageyev, Victor. Financial Analyst. 09 2011.

[33]. Abadi, T.M.(2014). Laporan Penganmbilan dan Pengukuran Sampel Timbulan Sampah dan komposis sampah Perkotaan Kota Samarinda dan Balikpapan. Samarinda, Samarinda Indonesia Dkpp.

[34].Federal Democratic Republic of Ethiopia (FDRE), "Solid Waste Management Proclamation ". Federal Negarit Gazeta of the FDRE Proclamation No. 15 3/2007. Addis Abebe, Ethiopia, 2010.

[35].Federal Democratic Republic of Ethiopia (FDRE), "Solid waste Management Proclamation", Federal Negerit Gezeta of the FDRE proclamation No. 513/2007. Addis Ababa, Ethiopia.

[36]. Green Environmental Consultant, "Implementing market-based municipal solid waste management study in Adama ". In collaboration with FDRE Ministry of Urban works and plan development and Adama city administration, Addis Ababa, Ethiopia, 2010.

[37]. UNDP, "Urban Agriculture: Food, Jobs and Sustainable Cities". UNDP Urban Harvest Working paperSeries , paper No.1. New York. 2004.

[38].National Meteorological Service Agency (NMSA), "*Annual Report",* Addis Ababa, Ethiopia.2006.

[39]. Central Statistical Authority, “Household Consumption and expenditure survey 2010/11”, Statistical Bulletin (No. 563). Addis Ababa, Ethiopia. 2012.

[40]. D. Wells, “Environmental policy: Abnormal Perspective to the Twenty First Century.” New Jersey, USA, 1996.

[41]. Mengist Hailemariam,“Solid Waste Management in Adama, Ethiopia Aspects and Challenges”. 2014

[42]. Balmer, Robert T., *Thermodynamics,* West Publishing Co., New York, 1990.

[43]. Bazhiser, Richard E. and Micheal R. Samuels, *Engineering Thermodynamics,* Prentice-Hall Publishing Co., New Jersey, 1977.

[44].Black, William Z, and James G. Hartley, *Thermodynamics: An Engineering Approach,* Third Edition, McGraw-Hill Publishing Co., New York, 1998.

[45]. Granet, Irving and Maurice Bluestein, *Thermodynamics and Heat power,* Allen and Bacon, Inc., Boston, 1980.

[46]. Haberman, William, L. and James E,A. John, Engineering *Thermodynamics*, *A*llen and Prentice-Hall Publishing Co., New jersey, 2000.

[47]. Huang, Francis F., Engineering *Thermodynamics, Fundamentals and Applications,* MacMillian Publishing Co., New York, 1976.

[48].Moran, Michael, J. and Howard N. Shapiro, *Fundamentals of Thermodynamics,* Fourth Edition, John Wiley and Sons Publishing Co., New York, 2000.

[49]. Rogers, G.F.C. and Y.R. Mayhew, *Engineering Thermodynamics, Work and Heat Transfer,* Fourth Edition, Addison Wesley Longman Lt, Essex, England, 1992.

[50]. Sonntag, Richard E., Claus Borgnakke, and Gordon J. Van Wylen, *Fundamentals of Thermodynamics,* Fifth Edition, John Wiley and Sons Publishing Co., New York, 1999.

[51]. Chih Wu, *Thermodynamics and heat powered cycles: A cognitive Engineering Approach* Nova Science Publishers, Inc, 2007.

[52]. Martin GmbH Wast-to-Energy Plant KHKW Zurich-Hagenholz Switzerland. http://www. martingmbh.de/

[53]. Thermoflex Software version 22 by Thrmoflow inc. (2012)

[54]. ENEA-Federambiente (2012) Report on energy recovery from municipal solid waste in Italy, 3rd edition. (In Italian)

[55].Bianchi M, Branchini L (2012) Advanced waste-to-energy power plant: integration with gas turbine. International conference applied energy, July 5-8, 2012, Suzhou, China paper ID: ICAE2012-A10330

[56].Bianchi m, Branchini L, De Pascale A (2014) Performance indexes and output allocation for multi-fuel energy systems. Energy Proc 45:32-41. Doi:10.1016/j. egypro. 2014.01.005

[57]. Bianchi M Branchini L, De Pascale A, Falchetti M, Fiore P (2014) Advanced waste-to-energy steam cycles. Energy proc 45:1205-1214. Doi: 10.1016/j. egypro. 2014.01.126

[58]. Gas Turbine World (2004-2005) GTW handbook, vol 24. Pequot, Southport, Pequot Publication

[59]. Bhargava Rk, Bianchi M, Campanari S, De Pascale A, di Montenegro GN, peretto AA (2010) Parametric thermodynamic evaluation of high performance gas turbine based power cycles. J Eng Gas Turbines power 132 (2). Article no. 022001. Doi:10.1115/1.3155782

[60]. Directive (22.11.2008) 2008/98/EC of the European parliament and of the council of 19 November 2008 on waste. Official Journal European Union OJL 312/3, 22.11.2008

[61]. CNIM and SENER (2005) Bizkaia waste to energy plant project, summary report. Contract No.BM 80/96 ES-PO

[62]. SENER Ingenieria y Sistemas S.A. High efficiency technologies applied for waste to energy (WTE)

[63].AZN and EPZ combination of a waste incineration plant and a combined cycle power plant. project no. BM/349/93/NL

[64].Branchini Lisa, "Waste-to-Energy Advanced Cycles and New Design Concepts for Efficient power plats" Springer International Publishing Switzerland, (2015).

[65].IEAWorld Energy Outlook (2010) http://www.worldenergyoutlook.org/media/weo2010.pdf.

[66].Branchini L, perez-Blanco H (2012) Handling wind variability using gas turbines. Proceedings ASME Turbo Expo.5 pp727-734. Doi:10.1115/GT2012-68045

[67]. Al-Mansoura F, Zuwala J (2010) An evaluation of biomass Co-firing in Europe. Biomass Bioenergy 34(5):620-381

[68]. Savolainen K (2003) co-firing of biomass is Coal-fired utility boilers. Appl Energy 74(3-4):369-381

[69]. Tillman DA (2000) Biomass cofiring: the technology, the experience, the combustion consequence. Biomass Bioenergy 19(6): 365-384

[70]. Agll et al., (2014). Study of energy recovery and power generation from alternative energy source. Case studies in Thermal Engineering, 4, PP. 92-98.

[71]. Anttila L., (2013). Waste-to-Energy Scenarios in the China Context, Degree Programmer in Environmental Engineering Master's Thesis, Lappeenranta University of Technology, Faculty of Technology. (Anttila, 2013)

[72]. ARTELIA, (2014). Solid Waste Management Project-strategic and Technical studies and works Supervision. Addis Ababa city Government- Ethio-French Cooperation. Addis Ababa.

[73] Aydi, A. (2012) Energy Recovery from a Muncipal Solid Waste (MSW) landfill Gas: A Tunisian Case study. Journal of waste water Treatment and Analysis, 03(04).

[74]. Balogun, b. (2017). Energy Recovery Possibilities from Municipal Solid Waste, in lagos southwest Nigeria, Degree program in energy Technology Master Thesis Lappeenranta University of Technology, Faculty of technology.

[75], Barun Kumar Das et al., (2014). Energy Recovery Potential from Municipal Solid waste in Rajshahi city by Landfill Technique. International Journal of Renewable Energy Research, Vol.4 No.2.

APPENDEX A

The most profitable steam parameters optimized in CYCLEPAD, MECH IN EXCEL, and Python software's are displayed in Table A1, Table A2 Table A3. The steam cycle is a theoretical and ideal system adapted to limitations of the system. The system model is shown in Figure A1.

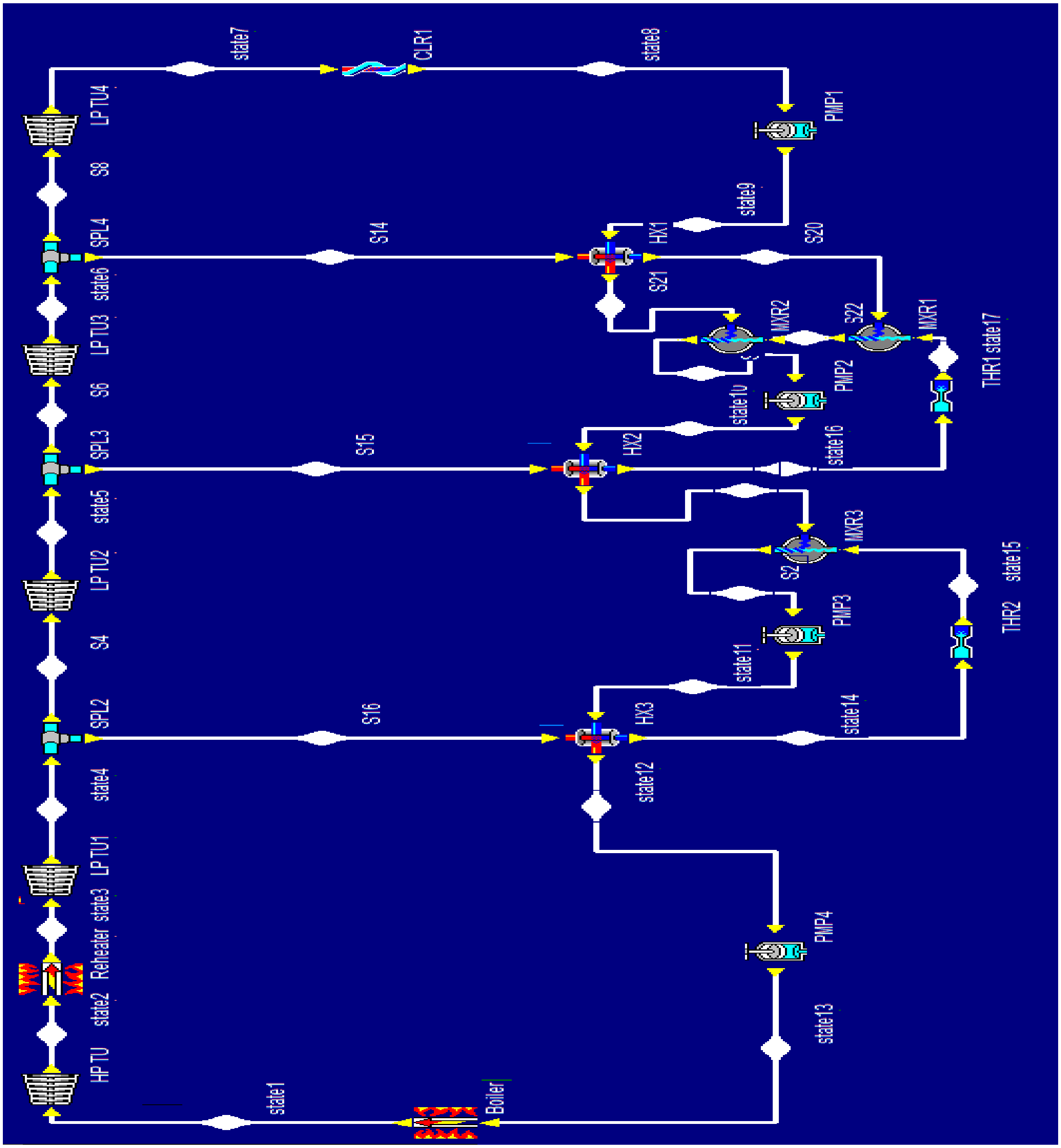


Figure A. 1 Steam cycle model in CYCLEPAD

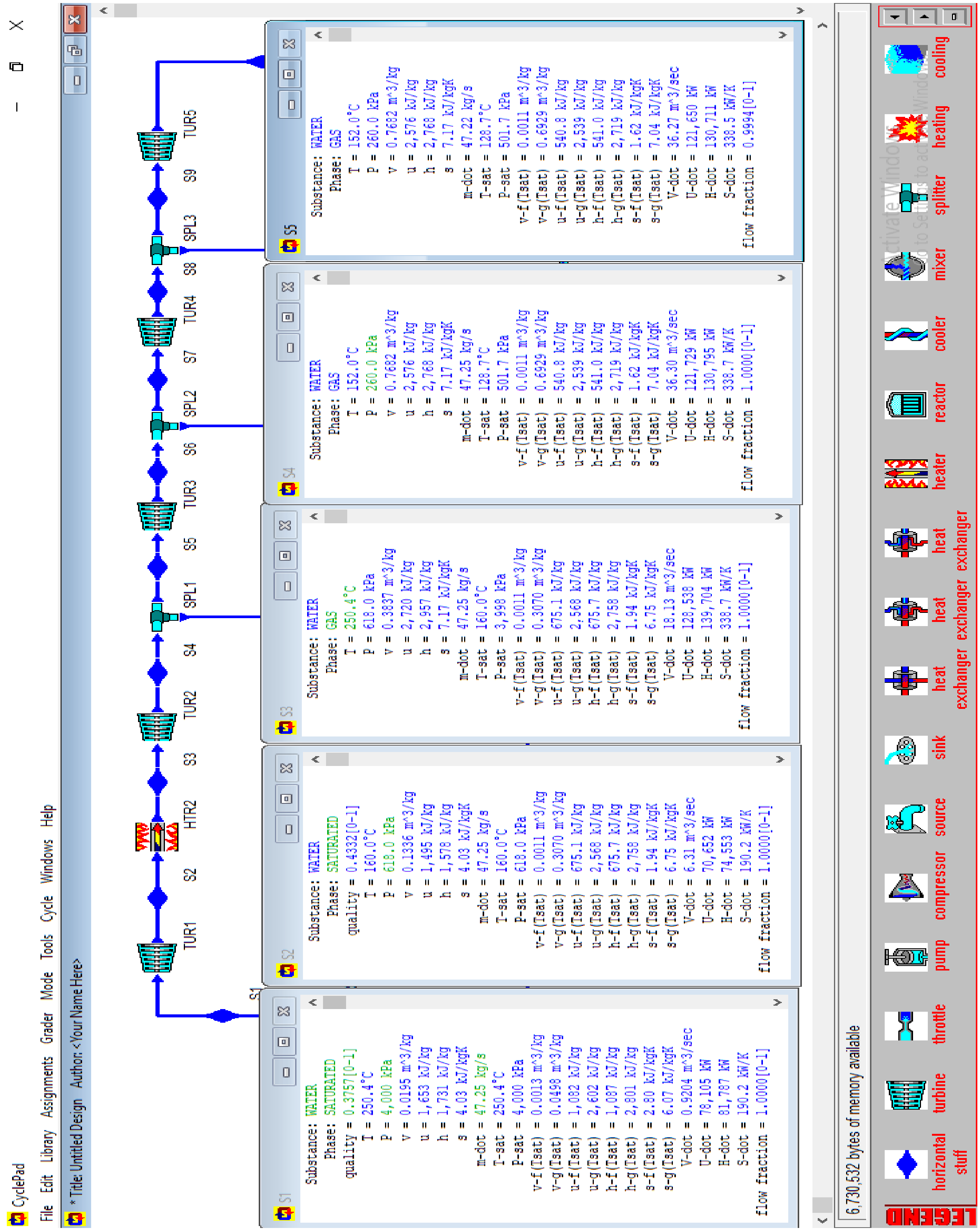
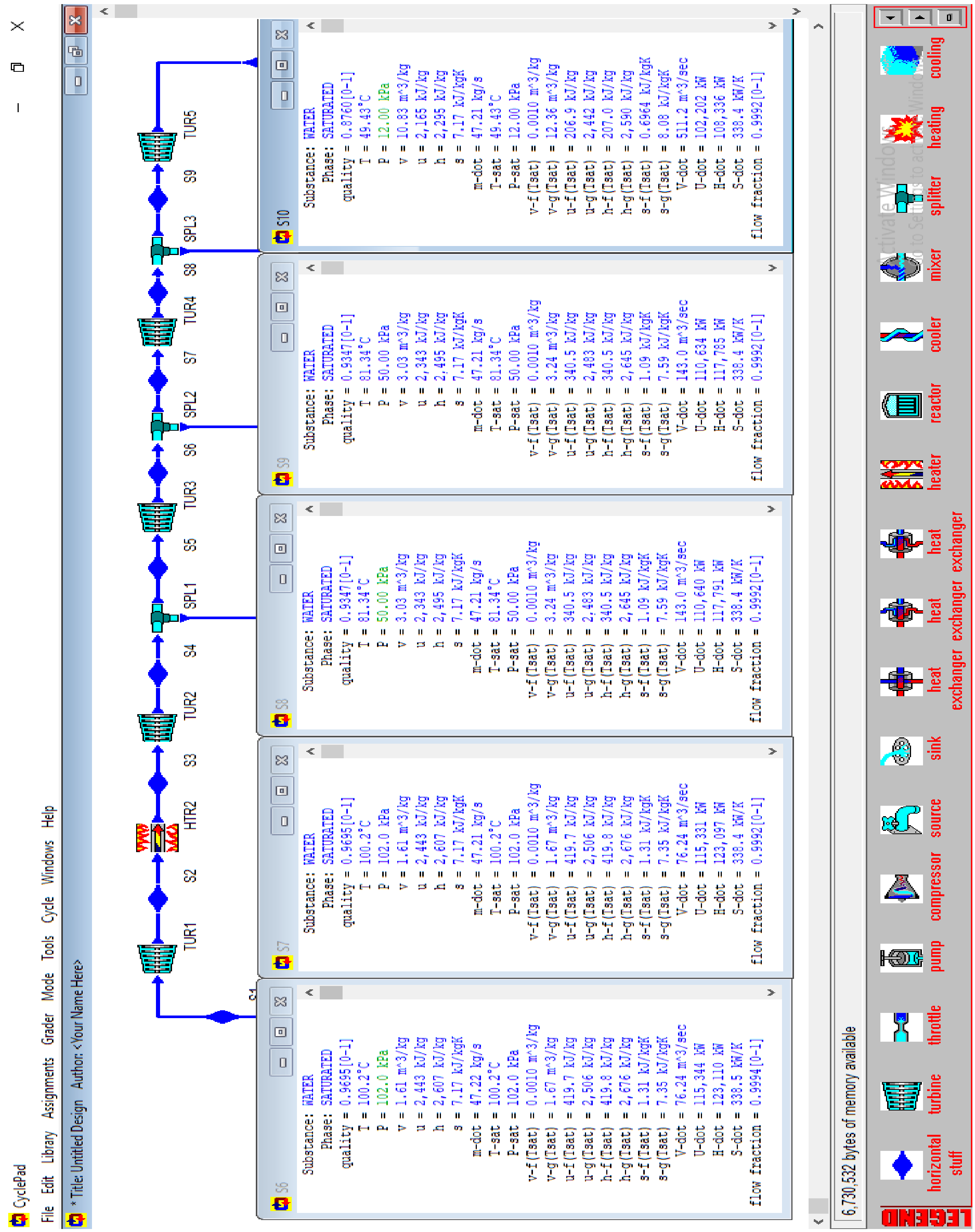


Figure A.2 Cycle Result and Measurement state 1-5 in CYCLEPAD



FigureA.3 Cycle Result and Measurement state 6-10 CYCLEPAD

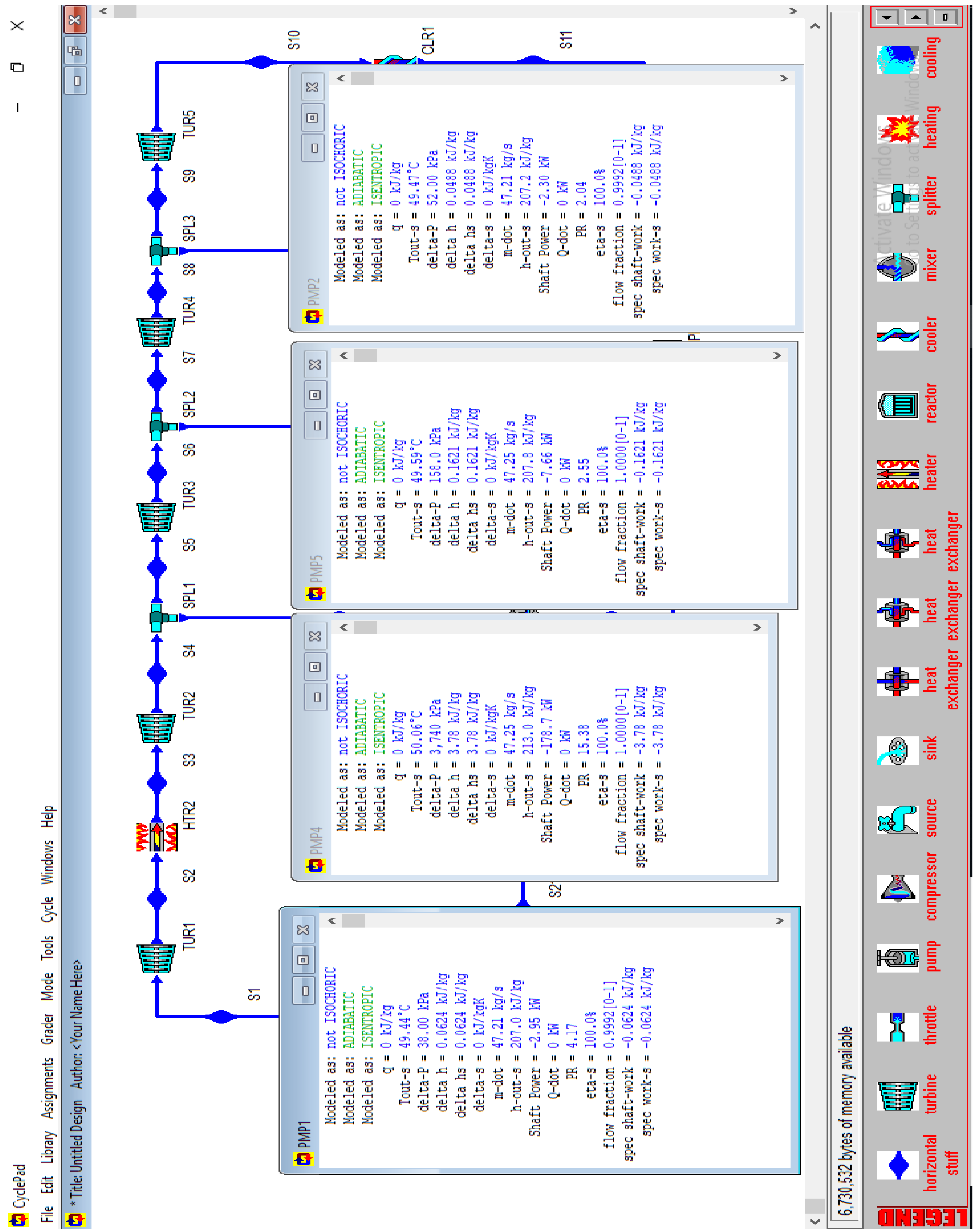


Figure A.4 Cycle Result and Measurement pump 1-4 in CYCLEPAD

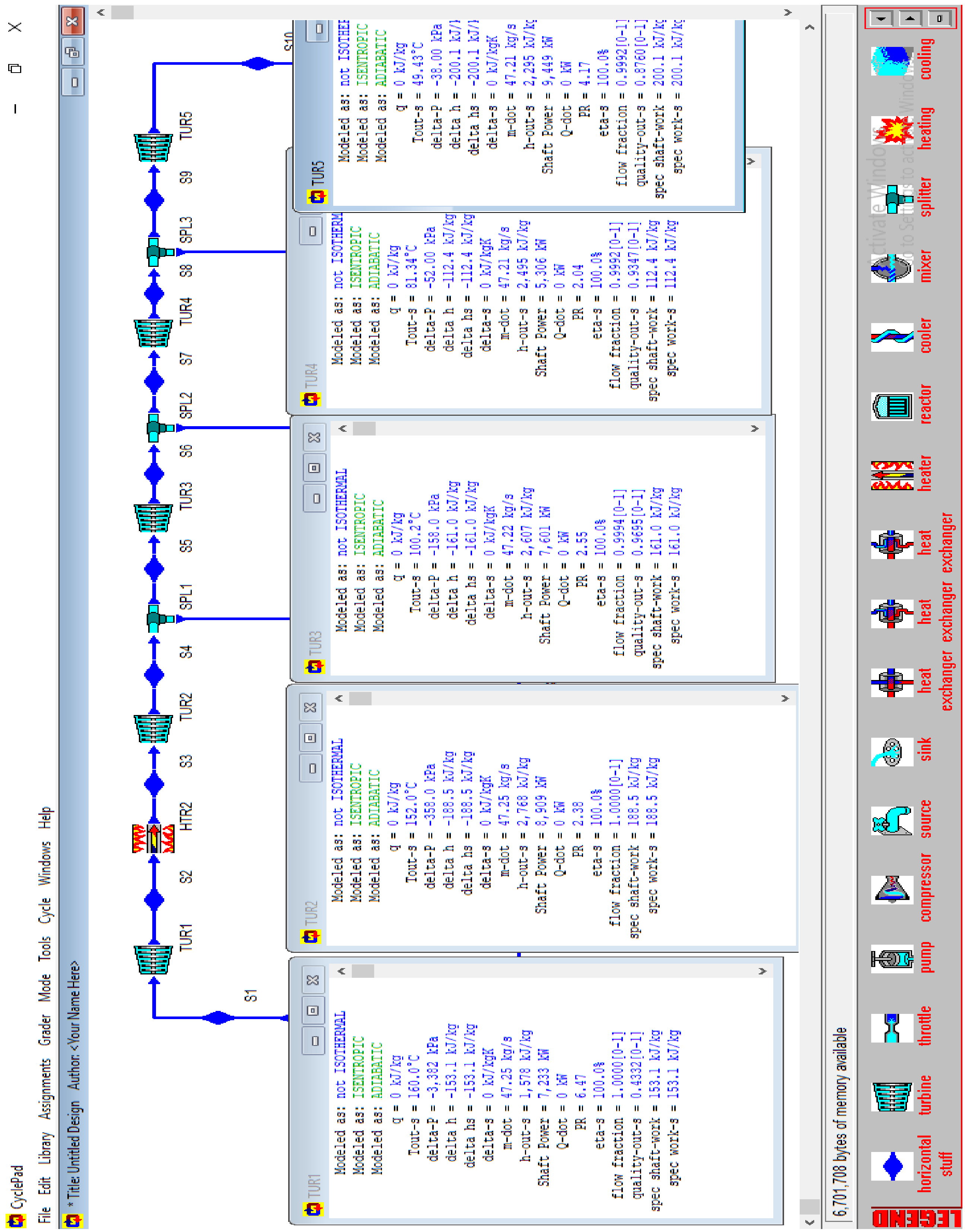


Figure A.5 Cycle Result and Measurement High pressure1 and Low pressure 1-4 inCYCLEPAD

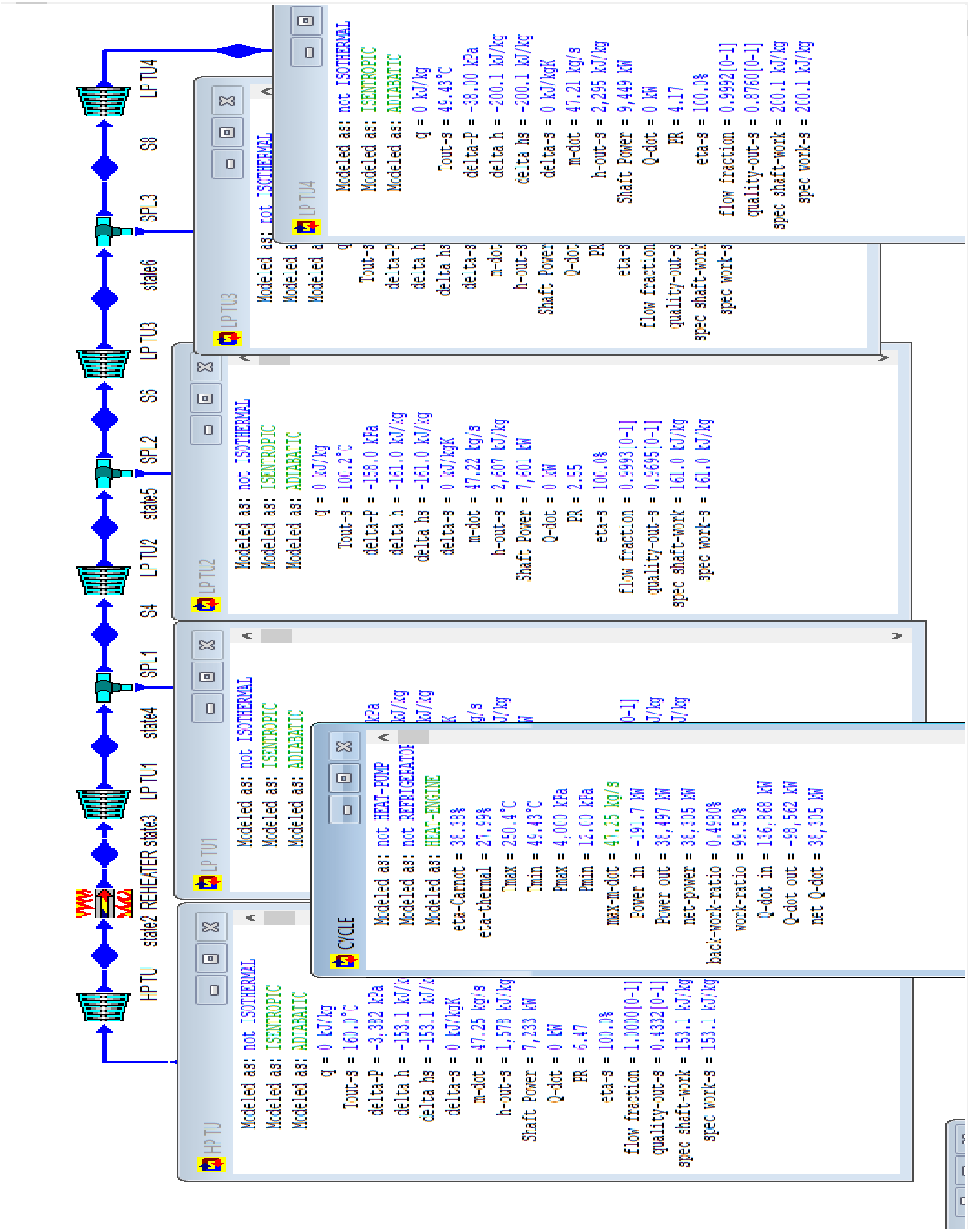


Figure A.6 Cycle Result and Measurement Heat engine and turbine in CYCLEPAD

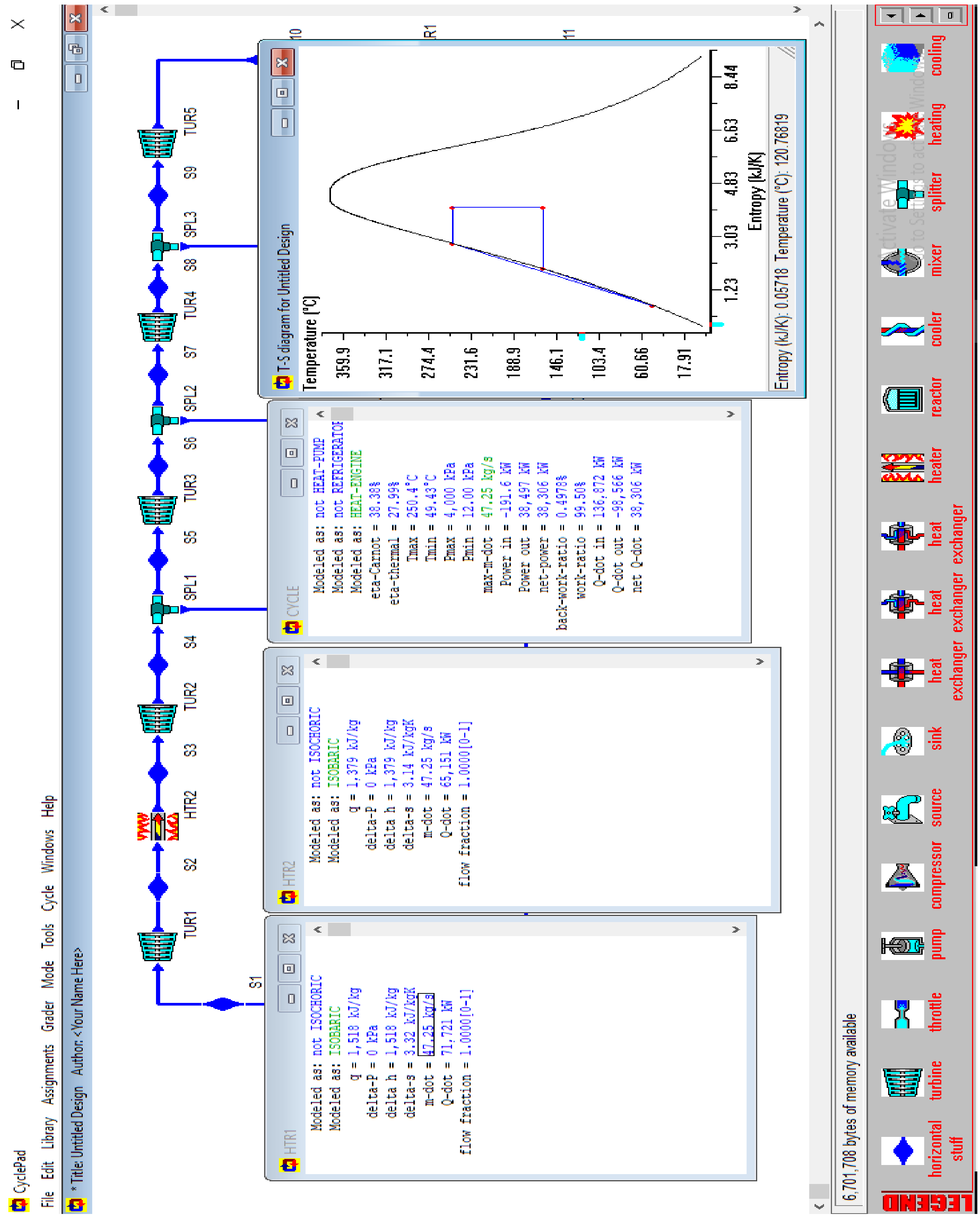


Figure A.7 Cycle Result and Measurement Boiler, TS diagram, Reheating and turbine in CYCLEPAD

The calculation procedure in MECH IN EXCLE, this calculation done based on Rankine steam cycle. The following Table 1 shows all the mathematical procedure.

Table A1: Mech in excel steam calculation

Fixed Parameter	*State or Node*	*Pressure*	*Kpa*
p,h	1	p_1	4000
p,s	2s	p_2s	618
p,h	2	p_2	618
p, Reheated	3	p_3	618
p,s	4s	p_4s	260
p,h	4	p_4	260
p,s	5s	p_5s	102
p,h	5	p_5	102
p,s	6s	p_6s	50
p,h	6	p_6	50
p,s	7s	p_7s	12
p,h	7	p_7	12
p,saturated	8	p_8	12
p,s	9s	p_9s	50
p,h	9	p_9	50
p,s	10s	p_10s	102
p,h	10	p_10	102
p,s	11s	p_11s	260
p,h	11	p_11	260
heat exchanger	Exch	p_12	260
p,s	13s	p_13s	4000
p,h	13	p_13	4000
p, saturated	14	p_14	260
p,h	15	p_15	102
p,saturated	16	p_16	102
p,h	17	p_17	50

Temperature	*C*	*Formula*	*Internal Energy*	*kJ/kg*
T_1	250.3575	=T_ph_H2O(p_1,h_1)	u_1	1529.0619
T_2S	159.9911	=T_hs_H2O(h_2s,s_2s)	u_2s	1390.0923
T_2	159.9911	=T_ps_H2O(p_2,s_2)	u_2	1407.6798
T_3	250.3575	Reheated	u_3	2721.4175
T_4S	153.8389	=T_pv_H2O(p_4s,v_4s)	u_4s	2579.6764
T_4	167.1182	=T_hs_H2O(h_4,s_4)	u_4	2600.8943
T_5S	100.1606	=T_hv_H2O(h_5s,v_5s)	u_5s	2465.5181
T_5	100.1602	=T_hs_H2O(h_5,s_5)	u_5	2488.8918
T_6S	81.31673	=T_hs_H2O(h_6s,s_6s)	u_6s	2387.3189
T_6	81.31661	=T_hv_H2O(h_6,v_6)	u_6	2403.3604
T_7S	49.41985	=T_hv_H2O(h_7s,v_7s)	u_7s	2219.8517
T_7	49.41986	=T_hs_H2O(h_7,s_7)	u_7	2248.8178
T_8	49.41978	=Tsat_p_H2O(p_8)	u_8	206.89859
T_9S	49.43076	=T_hs_H2O(h_9s,s_9s)	u_9s	206.88125
T_9	48.652	=T_hs_H2O(h_9,s_9)	u_9	206.72318
T_10S	46.84952	=T_hv_H2O(h_10s,v_10s)	u_10s	194.43612
T_10	46.85283	=T_hv_H2O(h_10,v_10)	u_10	206.94921
T_11S	46.8974	=T_hv_H2O(h_11s,v_11s)	u_11s	194.63464
T_11	49.46695	=T_hs_H2O(h_11,s_11)	u_11	207.00631
T_12	88.3433	heat exchange calculation	u_12	369.88186
T_13S	88.56693	=T_ph_H2O(p_13s,h_13s)	u_13s	361.11901
T_13	88.72569	=T_hs_H2O(h_13,s_13)	u_13	370.54759
T_14	128.7107	=Tsat_p_H2O(p_14)	u_14	540.60605
T_15	100.1597	=T_hs_H2O(h_15,s_15)	u_15	531.67726
T_16	100.1604	=Tsat_p_H2O(p_15)	u_16	419.66966
T_17	100.1622	=T_hs_H2O(h_16,s_16)	u_17	419.68085

Formula	***Volume***	***m^3/kg***	***Formula2***	***Quality***
=u_ph_H2O(p_1,h_1)	v_1	0.015517033	=v_ph_H2O(p_1,h_1)	x_1
=u_ph_H2O(p_2s,h_2s)	v_2s	0.00099985	=v_ph_H2O(p_2s,s_2s)	x_2s
=u_hv_H2O(h_2,v_2)	v_2	0.119482546	=v_hs_H2O(h_2,s_2)	x_2
=u_pT_H2O(p_3,T_3)	v_3	0.382454768	=v_pT_H2O(p_3,T_3)	x_3
=u_hv_H2O(h_4s,v_4s)	v_4s	0.741705488	=v_ph_H2O(p_4s,h_4s)	x_4s
=u_hs_H2O(h_4,s_4)	v_4	0.766969419	=v_ph_H2O(p_4,h_4)	x_4
=u_hs_H2O(h_5s,s_5s)	v_5s	1.63053016	=v_ph_H2O(p_5s,h_5s)	x_5s
=u_hv_H2O(h_5,v_5)	v_5	1.649160193	=v_hs_H2O(h_5,s_5)	x_5
=u_hv_H2O(h_6s,v_6s)	v_6s	3.095202562	=v_ph_H2O(p_6s,h_6s)	x_6s
=u_hv_H2O(h_6,v_6)	v_6	3.11946072	=v_hs_H2O(h_6,s_6)	x_6
=u_hv_H2O(h_7s,v_7s)	v_7s	11.13043407	=v_hs_H2O(h_7s,s_7s)	x_7s
=u_hs_H2O(h_7,s_7)	v_7	11.29058485	=v_hs_H2O(h_7,s_7)	x_7
=uL_p_H2O(p_8)	v_8	0.001011869	=vL_p_H2O(p_8)	x_8
=u_hs_H2O(h_9s,s_9s)	v_9s	0.001011859	=v_hs_H2O(h_9s,s_9s)	x_9s
=u_hs_H2O(h_9,s_9)	v_9	0.018382447	=v_hs_H2O(h_9,s_9)	x_9
=u_hv_H2O(h_10s,v_10s)	v_10s	0.001011837	=v_ph_H2O(p_10s,h_10s)	x_10s
=u_hs_H2O(h_10,s_10)	v_10	0.001011854	=v_hs_H2O(h_10,s_10)	x_10
=u_hv_H2O(h_11s,v_11s)	v_11s	0.001011776	=v_hs_H2O(h_11s,s_11s)	x_11s
=u_hs_H2O(h_11,s_11)	v_11	0.001011792	=v_hs_H2O(h_11,s_11)	x_11
=u_pT_H2O(p_12,T_12)	v_12	0.001034662	=v_pT_H2O(p_12,T_12)	x_12
=u_hv_H2O(h_13s,v_13s)	v_13s	0.001033011	=v_ph_H2O(p_13s,h_13s)	x_13s
=u_ph_H2O(p_13,h_13)	v_13	0.001033011	=v_pT_H2O(p_12s,T_12S)	x_13
=uL_p_H2O(p_14)	v_14	0.001068465	=vL_p_H2O(p_14)	x_14
=u_hs_H2O(h_15,s_15)	v_15	0.090260729	=v_hs_H2O(h_15,s_15)	x_15
=uL_p_H2O(p_15)	v_16	0.001043581	=vL_p_H2O(p_15)	x_16
=u_hs_H2O(h_16,s_16)	v_17	0.001043582	v_ph_H2O(p_16,h_16)	x_17

Value	Formula	Enthalpy	kJ/kg	Formula2
0.293967	=x_ph_H2O(p_1,h_1)	h_1	1591.13	from wast thermal value
0.3778503	=x_hs_H2O(h_2s,s_2s)	h_2s	1462.1769	=h_ps_H2O(p_2s,s_2s)
0.3871413	=x_hs_H2O(h_2,s_2)	h_2	1481.5199	=h_1-w_t1a
1	=x_pu_H2O(p_3,u_3)	h_3	2957.7745	=h_pT_H2O(p_3,T_3)
1	=x_hs_H2O(h_4s,s_4s)	h_4s	2772.5251	=h_ps_H2O(p_4s,s_4s)
1	=x_hs_H2O(h_4,s_4)	h_4	2800.3125	=h_3-w_st1a
0.9805003	=x_hs_H2O(h_5s,s_5s)	h_5s	2631.8327	=h_ps_H2O(p_5s,s_5s)
0.9917023	=x_hs_H2O(h_5,s_5)	h_5	2657.1047	=h_4-w_st2a
0.9552512	=x_hs_H2O(h_6s,s_6s)	h_6s	2542.0791	=h_ps_H2O(p_6s,s_6s)
0.9627375	=x_hs_H2O(h_6,s_6)	h_6	2559.3329	=h_5-w_st3a
0.9006166	=x_hs_H2O(h_7s,s_7s)	h_7s	2353.4175	=h_ps_H2O(p_7s,s_7s)
0.9135761	=x_hs_H2O(h_7,s_7)	h_7	2384.3048	=h_6-w_st4a
0	=x_pu_H2O(p_8,u_8)	h_8	206.91073	=hL_p_H2O(p_8)
0	=x_hs_H2O(h_9s,s_9s)	h_9s	206.93186	=h_ps_H2O(p_9s,s_9s)
0.0013559	=x_hs_H2O(h_9,s_9)	h_9	206.93558	=h_8+w_pt1a
0	=x_hs_H2O(h_10s,s_10s)	h_10s	207.01361	=h_ps_H2O(p_10s,s_10s)
0	=x_hs_H2O(h_10,s_10)	h_10	207.02737	=h_9+w_pt2a
0	=x_hs_H2O(h_11s,s_11s)	h_11s	207.21247	=h_ps_H2O(p_11s,s_11s)
0	=x_hs_H2O(h_11,s_11)	h_11	207.24513	=h_10+w_pt3a
0	=x_pu_H2O(p_12,u_12)	h_12	370.15087	=h_pT_H2O(p_12,T_12)
0	=x_hs_H2O(h_13s,s_13s)	h_13s	374.01757	=h_ps_H2O(p_13s,s_13s)
0	=x_hs_H2O(h_13,s_13)	h_13	374.69993	=h_12+w_pt4a
0	=x_pu_H2O(p_14,u_14)	h_14	540.88385	=hL_p_H2O(p_14)
0.0536828	=x_hs_H2O(h_15,s_15)	h_15	540.88385	h_15=h_14
0	=x_pu_H2O(p_16,u_16)	h_16	419.7761	=hL_p_H2O(p_16)
0.0016244	=x_hs_H2O(h_17,s_17)	h_17	419.7761	h_17=h_16

Entropy	kJ/kg-k	Formula
s_1	3.758823725	=s_ph_H2O(p_1,h_1)
s_2s	3.758823725	s_2s=s_1
s_2	3.803481218	=s_ph_H2O(p_2,h_2)
s_3	7.170258913	=s_ph_H2O(p_3,h_3)
s_4s	7.170258913	s_4s=s_3
s_4	7.234311595	=s_ph_H2O(p_4,h_4)
s_5s	7.234311595	s_5s=s_4
s_5	7.302008187	=s_ph_H2O(p_5,h_5)
s_6s	7.302008187	s_6s=s_5
s_6	7.350683472	=s_ph_H2O(p_6,h_6)
s_7s	7.350683472	s_7s=s_6
s_7	7.446437456	=s_ph_H2O(p_7,h_7)
s_8	0.696282563	=sL_p_H2O(p_8)
s_9s	0.696282563	s_9s=s_8
s_9	0.696372735	=s_ph_H2O(p_9,h_9)
s_10s	0.696372735	s_10s=s_9
s_10	0.696493178	=s_ph_H2O(p_10,h_10)
s_11s	0.696493178	s_11s=s_10
s_11	0.696669704	=s_ph_H2O(p_11,h_11)
s_12	1.173286249	=s_ph_H2O(p_12,h_12)
s_13s	1.173286249	s_13s=s_12
s_13	1.175130055	=s_ph_H2O(p_13,h_13)
s_14	1.620984194	=sL_p_H2O(p_14)
s_15	1.633240466	=s_ph_H2O(p_15,h_15)
s_16	1.30882646	=sL_p_H2O(p_15)
s_17	1.308846002	=s_ph_H2O(p_17,h_17)

Column1	Column2	Column3	Column4
work done in turbine one 1s	w_t1s	128.953072	KJ/kg
work done in turbine one 1a	w_t1a	109.610112	KJ/kg
efficiency of turbine and pump	Effi	0.85	value
work done in first stage turbine 1s	w_st1s	185.249418	KJ/kg
work done in first stage turbine 1a	w_st1a	157.462005	KJ/kg
work done in first stage turbine 2s	w_st2s	168.479813	KJ/kg
work done in first stage turbine 2a	w_st2a	143.207841	KJ/kg
work done in first stage turbine 3s	w_st3s	115.025625	KJ/kg
work done in first stage turbine 3a	w_st3a	97.7717813	KJ/kg
work done in first stage turbine 4s	w_st4s	205.915429	KJ/kg
work done in first stage turbine 4a	w_st4a	175.028114	KJ/kg
work required for first pump 1s	w_pt1s	0.02112088	KJ/kg
work required for first pump 1a	w_pt1a	0.02484809	KJ/kg
work required for second pump 2s	w_pt2s	0.07802298	KJ/kg
work required for second pump 2a	w_pt2a	0.09179174	KJ/kg
work required for third pump 3s	w_pt3s	0.18509055	KJ/kg
work required for third pump 3a	w_pt3a	0.21775359	KJ/kg
work required for fourth pump 4s	w_pt4s	3.86669862	KJ/kg
work required for fourth pump 4a	w_pt4a	4.5490572	KJ/kg
work required total	w_rtotal	4.88345062	KJ/kg
work net	w_net	678.196403	KJ/kg
work required for pump total ideal	w_rnet ideal	4.88345062	KJ/kg
work total ideal	w_net ideal	803.623357	KJ/kg
work done net	w_total	683.079854	KJ/kg
work net ideal	w_total net ideal	798.739907	KJ/kg
mass flow rate	dm_dt	47.25	kg/s
power out put ideal	power ideal	37740.4606	kw
power out put	power	32044.7801	KW
power out put	power	32.0447801	MW
mass fraction of the system	y_fraction	0.06716066	dimension less
mass fraction of the system	z_fraction	0.01163018	dimension less
mass fraction of the system	m_fraction	0.00489473	dimension less
mass fraction of the system	x_fraction	0.91631443	dimension less

FORMULA OF WORK AND POWER
=h_1-h_2s
=w_t1s*effi
from litrature review
=h_3-h_4s
=w_st1s*effi
=h_4-h_5s
=w_st2s*effi
=h_5-h_6s
=w_st3s*effi
=h_6-h_7s
=w_st4s*effi
=h_9s-h_8
=w_pt1s/effi
=h_10s-h_9
=w_pt2s/effi
=h_11s-h_10
=w_pt3s/effi
=h_13s-h_12
=w_pt4s/effi
=w_pt1a+w_pt2a+w_pt3a+w_pt4a
=w_total-w_rtotal
=w_pt1a+w_pt2a+w_pt3a+w_pt4a
=w_t1s+w_st1s+w_st2s+w_st3s+w_st4s
=w_st1a+w_st3a+w_t1a+w_st2a+w_st4a
=w_net_ideal-w_rnet_ideal
from litrature review
=w_total_net_ideal*dm_dt
=w_net*dm_dt
=w_net*dm_dt
=(h_12-h_11)/(h_4-h_13)
=(h_10-h_11+y_fraction*(h_14-h_10))/(h_5-(h_15+h_10))
=(h_10+z_fraction*(h_9-h_16)-h_9+y_fraction*h_9)/(h_6-h_9)
=1-y_fraction-z_fraction-m_fraction

The calculation procedure of Solar assisted in MECH IN EXCLE, this calculation done based on Rankine steam cycle. The following Table A2 shows all the mathematical procedure.

Table A2: Solar assisted in MECH EXCEL steam calculation

Fixed Parameter	***State or Node***	***Pressure***	***Kpa***
p,h	1	p_1	4000
p,s	2s	p_2s	618
p,h	2	p_2	618
p, Reheated	3	p_3	618
p,s	4s	p_4s	260
p,h	4	p_4	260
p,s	5s	p_5s	102
p,h	5	p_5	102
p,s	6s	p_6s	50
p,h	6	p_6	50
p,s	7s	p_7s	12
p,h	7	p_7	12
p,saturated	8	p_8	12
p,s	9s	p_9s	50
p,h	9	p_9	50
p,s	10s	p_10s	102
p,h	10	p_10	102
p,s	11s	p_11s	260
p,h	11	p_11	260
heat exchanger	Exch	p_12	260
p,s	13s	p_13s	4000
p,h	13	p_13	4000
p, saturated	14	p_14	260
p,h	15	p_15	102
p,saturated	16	p_16	102
p,h	17	p_17	50

Temperature	*C*	*Formula*	*Internal Energy*
T_1	250.3575	=T_ph_H2O(p_1,h_1)	u_1
T_2S	159.9913	=T_hs_H2O(h_2s,s_2s)	u_2s
T_2	159.9911	=T_ps_H2O(p_2,s_2)	u_2
T_3	250.3575	Reheated	u_3
T_4S	153.8389	=T_pv_H2O(p_4s,v_4s)	u_4s
T_4	167.1182	=T_hs_H2O(h_4,s_4)	u_4
T_5S	100.1606	=T_hv_H2O(h_5s,v_5s)	u_5s
T_5	100.1602	=T_hs_H2O(h_5,s_5)	u_5
T_6S	81.31673	=T_hs_H2O(h_6s,s_6s)	u_6s
T_6	81.31661	=T_hv_H2O(h_6,v_6)	u_6
T_7S	49.41985	=T_hv_H2O(h_7s,v_7s)	u_7s
T_7	49.41986	=T_hs_H2O(h_7,s_7)	u_7
T_8	49.41978	=Tsat_p_H2O(p_8)	u_8
T_9S	49.43076	=T_hs_H2O(h_9s,s_9s)	u_9s
T_9	48.652	=T_hs_H2O(h_9,s_9)	u_9
T_10S	46.84952	=T_hv_H2O(h_10s,v_10s)	u_10s
T_10	46.85283	=T_hv_H2O(h_10,v_10)	u_10
T_11S	46.8974	=T_hv_H2O(h_11s,v_11s)	u_11s
T_11	49.46695	=T_hs_H2O(h_11,s_11)	u_11
T_12	88.3433	heat exchange calculation	u_12
T_13S	88.56693	=T_ph_H2O(p_13s,h_13s)	u_13s
T_13	88.72569	=T_hs_H2O(h_13,s_13)	u_13
T_14	128.7107	=Tsat_p_H2O(p_14)	u_14
T_15	100.1597	=T_hs_H2O(h_15,s_15)	u_15
T_16	100.1604	=Tsat_p_H2O(p_15)	u_16
T_17	100.1622	=T_hs_H2O(h_16,s_16)	u_17

kJ/kg	Formula	Volume	m^3/kg	Formula2
1653.2305	=u_ph_H2O(p_1,h_1)	v_1	0.019482585	=v_ph_H2O(p_1,h_1)
1495.4345	=u_ph_H2O(p_2s,h_2s)	v_2s	0.000999846	=v_ph_H2O(p_2s,s_2s)
1516.3186	=u_hv_H2O(h_2,v_2)	v_2	0.137032237	=v_hs_H2O(h_2,s_2)
2721.4175	=u_pT_H2O(p_3,T_3)	v_3	0.382454768	=v_pT_H2O(p_3,T_3)
2579.6764	=u_hv_H2O(h_4s,v_4s)	v_4s	0.741705488	=v_ph_H2O(p_4s,h_4s)
2600.8943	=u_hs_H2O(h_4,s_4)	v_4	0.766969419	=v_ph_H2O(p_4,h_4)
2465.5181	=u_hs_H2O(h_5s,s_5s)	v_5s	1.63053016	=v_ph_H2O(p_5s,h_5s)
2488.8918	=u_hv_H2O(h_5,v_5)	v_5	1.649160193	=v_hs_H2O(h_5,s_5)
2387.3189	=u_hv_H2O(h_6s,v_6s)	v_6s	3.095202562	=v_ph_H2O(p_6s,h_6s)
2403.3604	=u_hv_H2O(h_6,v_6)	v_6	3.11946072	=v_hs_H2O(h_6,s_6)
2219.8517	=u_hv_H2O(h_7s,v_7s)	v_7s	11.13043407	=v_hs_H2O(h_7s,s_7s)
2248.8178	=u_hs_H2O(h_7,s_7)	v_7	11.29058485	=v_hs_H2O(h_7,s_7)
206.89859	=uL_p_H2O(p_8)	v_8	0.001011869	=vL_p_H2O(p_8)
206.88125	=u_hs_H2O(h_9s,s_9s)	v_9s	0.001011859	=v_hs_H2O(h_9s,s_9s)
206.72318	=u_hs_H2O(h_9,s_9)	v_9	0.018382447	=v_hs_H2O(h_9,s_9)
194.43612	=u_hv_H2O(h_10s,v_10s)	v_10s	0.001011837	=v_ph_H2O(p_10s,h_10s)
206.94921	=u_hs_H2O(h_10,s_10)	v_10	0.001011854	=v_hs_H2O(h_10,s_10)
194.63464	=u_hv_H2O(h_11s,v_11s)	v_11s	0.001011776	=v_hs_H2O(h_11s,s_11s)
207.00631	=u_hs_H2O(h_11,s_11)	v_11	0.001011792	=v_hs_H2O(h_11,s_11)
369.88186	=u_pT_H2O(p_12,T_12)	v_12	0.001034662	=v_pT_H2O(p_12,T_12)
361.11901	=u_hv_H2O(h_13s,v_13s)	v_13s	0.001033011	=v_ph_H2O(p_13s,h_13s)
370.54759	=u_ph_H2O(p_13,h_13)	v_13	0.001033011	=v_pT_H2O(p_12s,T_12S)
540.60605	=uL_p_H2O(p_14)	v_14	0.001068465	=vL_p_H2O(p_14)
531.67726	=u_hs_H2O(h_15,s_15)	v_15	0.090260729	=v_hs_H2O(h_15,s_15)
419.66966	=uL_p_H2O(p_15)	v_16	0.001043581	=vL_p_H2O(p_15)
419.68085	=u_hs_H2O(h_16,s_16)	v_17	0.001043582	v_ph_H2O(p_16,h_16)

Quality	Value	Formula	Enthalpy	kJ/kg
x_1	0.3756904	=x_ph_H2O(p_1,h_1)	h_1	1731.1608
x_2s	0.433501	=x_hs_H2O(h_2s,s_2s)	h_2s	1578.0357
x_2	0.4445338	=x_hs_H2O(h_2,s_2)	h_2	1601.0044
x_3	1	=x_pu_H2O(p_3,u_3)	h_3	2957.7745
x_4s	1	=x_hs_H2O(h_4s,s_4s)	h_4s	2772.5251
x_4	1	=x_hs_H2O(h_4,s_4)	h_4	2800.3125
x_5s	0.9805003	=x_hs_H2O(h_5s,s_5s)	h_5s	2631.8327
x_5	0.9917023	=x_hs_H2O(h_5,s_5)	h_5	2657.1047
x_6s	0.9552512	=x_hs_H2O(h_6s,s_6s)	h_6s	2542.0791
x_6	0.9627375	=x_hs_H2O(h_6,s_6)	h_6	2559.3329
x_7s	0.9006166	=x_hs_H2O(h_7s,s_7s)	h_7s	2353.4175
x_7	0.9135761	=x_hs_H2O(h_7,s_7)	h_7	2384.3048
x_8	0	=x_pu_H2O(p_8,u_8)	h_8	206.91073
x_9s	0	=x_hs_H2O(h_9s,s_9s)	h_9s	206.93186
x_9	0.0013559	=x_hs_H2O(h_9,s_9)	h_9	206.93558
x_10s	0	=x_hs_H2O(h_10s,s_10s)	h_10s	207.01361
x_10	0	=x_hs_H2O(h_10,s_10)	h_10	207.02737
x_11s	0	=x_hs_H2O(h_11s,s_11s)	h_11s	207.21247
x_11	0	=x_hs_H2O(h_11,s_11)	h_11	207.24513
x_12	0	=x_pu_H2O(p_12,u_12)	h_12	370.15087
x_13s	0	=x_hs_H2O(h_13s,s_13s)	h_13s	374.01757
x_13	0	=x_hs_H2O(h_13,s_13)	h_13	374.69993
x_14	0	=x_pu_H2O(p_14,u_14)	h_14	540.88385
x_15	0.0536828	=x_hs_H2O(h_15,s_15)	h_15	540.88385
x_16	0	=x_pu_H2O(p_16,u_16)	h_16	419.7761
x_17	0.0016244	=x_hs_H2O(h_17,s_17)	h_17	419.7761

Formula	Entropy	kJ/kg-k	Formula2
from wast thermal value	s_1	4.026309158	=s_ph_H2O(p_1,h_1)
=h_ps_H2O(p_2s,s_2s)	s_2s	4.026309158	s_2s=s_1
=h_1-w_t1a	s_2	4.079337636	=s_ph_H2O(p_2,h_2)
=h_pT_H2O(p_3,T_3)	s_3	7.170258913	=s_ph_H2O(p_3,h_3)
=h_ps_H2O(p_4s,s_4s)	s_4s	7.170258913	s_4s=s_3
=h_3-w_st1a	s_4	7.234311595	=s_ph_H2O(p_4,h_4)
=h_ps_H2O(p_5s,s_5s)	s_5s	7.234311595	s_5s=s_4
=h_4-w_st2a	s_5	7.302008187	=s_ph_H2O(p_5,h_5)
=h_ps_H2O(p_6s,s_6s)	s_6s	7.302008187	s_6s=s_5
=h_5-w_st3a	s_6	7.350683472	=s_ph_H2O(p_6,h_6)
=h_ps_H2O(p_7s,s_7s)	s_7s	7.350683472	s_7s=s_6
=h_6-w_st4a	s_7	7.446437456	=s_ph_H2O(p_7,h_7)
=hL_p_H2O(p_8)	s_8	0.696282563	=sL_p_H2O(p_8)
=h_ps_H2O(p_9s,s_9s)	s_9s	0.696282563	s_9s=s_8
=h_8+w_pt1a	s_9	0.696372735	=s_ph_H2O(p_9,h_9)
=h_ps_H2O(p_10s,s_10s)	s_10s	0.696372735	s_10s=s_9
=h_9+w_pt2a	s_10	0.696493178	=s_ph_H2O(p_10,h_10)
=h_ps_H2O(p_11s,s_11s)	s_11s	0.696493178	s_11s=s_10
=h_10+w_pt3a	s_11	0.696669704	=s_ph_H2O(p_11,h_11)
=h_pT_H2O(p_12,T_12)	s_12	1.173286249	=s_ph_H2O(p_12,h_12)
=h_ps_H2O(p_13s,s_13s)	s_13s	1.173286249	s_13s=s_12
=h_12+w_pt4a	s_13	1.175130055	=s_ph_H2O(p_13,h_13)
=hL_p_H2O(p_14)	s_14	1.620984194	=sL_p_H2O(p_14)
h_15=h_14	s_15	1.633240466	=s_ph_H2O(p_15,h_15)
=hL_p_H2O(p_16)	s_16	1.30882646	=sL_p_H2O(p_15)
h_17=h_16	s_17	1.308846002	=s_ph_H2O(p_17,h_17)

Work done	Formula	value	Unite
work done in turbine one 1s	w_t1s	153.125146	KJ/kg
work done in turbine one 1a	w_t1a	130.156374	KJ/kg
efficiency of turbine and pump	Effi	0.85	Value
work done in first stage turbine 1s	w_st1s	185.249418	KJ/kg
work done in first stage turbine 1a	w_st1a	157.462005	KJ/kg
work done in first stage turbine 2s	w_st2s	168.479813	KJ/kg
work done in first stage turbine 2a	w_st2a	143.207841	KJ/kg
work done in first stage turbine 3s	w_st3s	115.025625	KJ/kg
work done in first stage turbine 3a	w_st3a	97.7717813	KJ/kg
work done in first stage turbine 4s	w_st4s	205.915429	KJ/kg
work done in first stage turbine 4a	w_st4a	175.028114	KJ/kg
work required for first pump 1s	w_pt1s	0.02112088	KJ/kg
work required for first pump 1a	w_pt1a	0.02484809	KJ/kg
work required for second pump 2s	w_pt2s	0.07802298	KJ/kg
work required for second pump 2a	w_pt2a	0.09179174	KJ/kg
work required for third pump 3s	w_pt3s	0.18509055	KJ/kg
work required for third pump 3a	w_pt3a	0.21775359	KJ/kg
work required for fourth pump 4s	w_pt4s	3.86669862	KJ/kg
work required for fourth pump 4a	w_pt4a	4.5490572	KJ/kg
work required total	w_rtotal	4.88345062	KJ/kg
work net	w_net	698.742666	KJ/kg
work required for pump total ideal	w_rnet ideal	4.88345062	KJ/kg
work total ideal	w_net ideal	827.795431	KJ/kg
work done net	w_total	703.626116	KJ/kg
work net ideal	w_total net ideal	822.911981	KJ/kg
mass flow rate	dm_dt	47.25	kg/s
power out put ideal	power ideal	38882.5911	Kw
power out put	Power	33015.591	KW
power out put	Power	33.015591	MW
mass fraction of the system	y_fraction	0.06716066	dimension less
mass fraction of the system	z_fraction	0.01163018	dimension less
mass fraction of the system	m_fraction	0.00489473	dimension less
mass fraction of the system	x_fraction	0.91631443	dimension less

Formula
=h_1-h_2s
=w_t1s*effi
from litrature review
=h_3-h_4s
=w_st1s*effi
=h_4-h_5s
=w_st2s*effi
=h_5-h_6s
=w_st3s*effi
=h_6-h_7s
=w_st4s*effi
=h_9s-h_8
=w_pt1s/effi
=h_10s-h_9
=w_pt2s/effi
=h_11s-h_10
=w_pt3s/effi
=h_13s-h_12
=w_pt4s/effi
=w_pt1a+w_pt2a+w_pt3a+w_pt4a
=w_total-w_rtotal
=w_pt1a+w_pt2a+w_pt3a+w_pt4a
=w_t1s+w_st1s+w_st2s+w_st3s+w_st4s
=w_st1a+w_st3a+w_t1a+w_st2a+w_st4a
=w_net_ideal-w_rnet_ideal
from litrature review
=w_total_net_ideal*dm_dt
=w_net*dm_dt
=w_net*dm_dt
=(h_12-h_11)/(h_4-h_13)
=(h_10-h_11+y_fraction*(h_14-h_10))/(h_5-(h_15+h_10))
=(h_10+z_fraction*(h_9-h_16)-h_9+y_fraction*h_9)/(h_6-h_9)

The calculation procedure in PYTHON, this calculation done based on Rankine steam cycle. The following Figure A.9

```
# -*- coding: utf-8 -*-
"""
Created on Wed Jul 17 15:05:28 2019

@author: REDWAN ALI USMAN

"""
from iapws import IAPWS95
from numpy import *
#state 1,  Fixed parameter P,T
steam=IAPWS95(P=4, h=1591.13)         #This value come from calorific value of waste. enthalpy from waste thermal h_1 in KJ/kg
print(steam.v,steam.x,steam.s)        #By using the above value we gate volume v_1 in m^/kg and quality x_1 is dimension less an
print(steam.T,steam.u)                #Temperature T_1 in K and Internal Energy u_1 in kJ/kg
#state 2s, Fixed parameter P,s
steam=IAPWS95(P=0.618, s=4.0263024)   #Becuase of constant entropy and given pressure p_2s in Mpa and s_2s=s_1 in kJ/kg*k
print(steam.h,steam.u)                #specific enthalpy h_2s in kJ/kg, specific internal energy u_2s kJ/kg.
print(steam.v, steam.x,steam.T)       #specific volume v_2s,qaulity x_2s its value is false, and Temperature T_2sin K
h_1=1731.161                         #specific enthalpy in kJ/kg
h_2s=1578.0149969                     #specific enthalpy in kJ/kg
w_1s=h_1-h_2s                         #specific work done in turbine one ideal in kJ/kg
effi=0.85                             #efficiency of turbine
w_1a=effi*w_1s                        #specific work done in turbine one in actual kJ/kg
print(w_1a)                           #specific work in turbine one in actual kJ/kg
h_2=h_1- w_1a                         #specific enthalpy in kJ/kg
```

```
steam=IAPWS95(P=0.618, T=523.50404528)    #Reheated and Temperature T_3 back to its initial point with constant pressure P_3
print(steam.v,steam.x,steam.s)            #specific volume v_3,quality its value is false, and Entropy
print(steam.h,steam.u)                    #specific enthalpy h_3, and Enternal energy u_3 in kJ/kg
#state 4s, Fixed parameter p,s
steam=IAPWS95(P=0.260, s=7.17010937811)    #Becuase of constant entropy and given pressure p_4s in Mpa and s_4s=s_3 in kJ/kg*k
print(steam.h,steam.u)                     #specific enthalpy h_4s in kJ/kg, specific internal energy u_4s kJ/kg.
print(steam.v, steam.x,steam.T)            #specific volume v_4s,qaulity x_4s its value is false, and Temperature T_4sin K
#state 4, Fixed parameter p,h
h_4s=2772.4451119                          #specific enthalpy in kJ/kg
h_3=2957.664024                            #specific enthalpy in kJ/kg
w_2s=h_3-h_4s                              #specific work done by first stage turbine  ideal in kJ/kg
w_2a=effi*w_2s                             #specific work done by fist state turbine  actual in kJ/kg
h_4=h_3-w_2a                               #specific enthalpy in kJ/kg
steam=IAPWS95(P=0.260, h=h_4)              #pressure p_4 in Mpa and specific enthalpy h_4 in kJ/kg
print(steam.T,steam.u,steam.x)             #Temperature T_4 in K, Internal energy u_4 in kJ/kg, quality its value is false
print(steam.v,steam.s)                     #specific volume v_4 in m^3/kg and Entropy s_4 in kJ/kg*k
#state 5s, Fixed parameter p,s
steam=IAPWS95(P=0.102, s=7.234192483) #Becuase of constant entropy and given pressure p_5s in Mpa and s_5s=s_4 in kJ/kg*k
print(steam.h,steam.u)                #specific enthalpy h_5s in kJ/kg, specific internal energy u_5s kJ/kg.
print(steam.v, steam.x,steam.T)       #specific volume v_5s,qaulity x_5s its value is false, and Temperature T_5s in K
#state 5, Fixed parameter p,h
h_5s=2631.770537                      #specific enthalpy in kJ/kg
w_3s=h_4-h_5s                         #specific work done by second stage turbine  ideal in kJ/kg
w_3a=effi*w_3s                        #specific work done by second stage turbine  ideal in kJ/kg
```

```
print(steam.h,steam.u)              #specific enthalpy h_6s in kJ/kg, specific internal energy u_6s kJ/kg.
print(steam.v, steam.x,steam.T)     #specific volume v_6s,qaulity x_6s its value is false, and Temperature T_6sin K
#state 6, Fixed parameter p,h
h_6s=2542.0226404                   #specific enthalpy in kJ/kg
w_4s=h_5-h_6s                       #specific work done by fourth stage turbine  ideal in kJ/kg
w_4a=effi*w_4s                      #specific work done by fourth stage turbine  ide in kJ/kg
h_6=h_5-w_4a                        #specific enthalpy in kJ/kg
steam=IAPWS95(P=0.050, h=h_6)       #pressure p_6 in Mpa and specific enthalpy h_6 in kJ/kg
print(steam.T,steam.u,steam.x)      #Temperature T_6 in K, Internal energy u_6 in kJ/kg, quality its value is false
print(steam.v,steam.s)              #specific volume v_6 in m^3/kg and Entropy s_6 in kJ/kg*k
#state 7s, Fixed parameter p,s
steam=IAPWS95(P=0.012, s=7.350552194) #Becuase of constant entropy and given pressure p_7s in Mpa and s_7s=s_5 in kJ/kg*k
print(steam.h,steam.u)              #specific enthalpy h_7s in kJ/kg, specific internal energy u_7s kJ/kg.
print(steam.v, steam.x,steam.T)     #specific volume v_7s,qaulity x_7s its value is false, and Temperature T_7sin K
#state 7 Fixed parameter p,h
h_7s=2369.8435890                   #specific enthalpy in kJ/kg
w_5s=h_6-h_7s                       #specific work done by fourth stage turbine  ideal in kJ/kg
w_5a=effi*w_5s                      #specific work done by fourth stage turbine  ide in kJ/kg
h_7=h_6-w_5a                        #specific enthalpy in kJ/k
steam=IAPWS95(P=0.012, h=h_7)       #pressure p_7 in Mpa and specific enthalpy h_7 in kJ/kg
print(steam.T,steam.u,steam.x)      #Temperature T_7 in K, Internal energy u_7 in kJ/kg, quality its value is false
print(steam.v,steam.s)              #specific volume v_7 in m^3/kg and Entropy s_7 in kJ/kg*k
#state 8, Fixed parameter p,saturated
```

```
print(sat_steam.v,sat_steam.s)              #specific volume v_8 in m^3/kg and Entropy s_8 in kJ/kg*k
#state 9s, Fixed parameter p,s
steam=IAPWS95(P=0.050, s=0.696279580)  #Becuase of constant entropy and given pressure p_8s in Mpa and s_8s=s_7 in kJ/kg*k
print(steam.h,steam.u)                 #specific enthalpy h_8s in kJ/kg, specific internal energy u_8s kJ/kg.
print(steam.v, steam.x,steam.T)        #specific volume v_8s,qaulity x_8s its value is false, and Temperature T_8sin K
#state 9, Fixed parameter p,h
h_9s=206.94903427                     #specific enthalpy in kJ/kg
h_8=206.91058331
w_p1s=h_9s-h_8                        #specific work done by fourth stage turbine  ideal in kJ/kg
w_p1a=w_p1s/effi                      #specific work done by fourth stage turbine  ide in kJ/kg
h_9=h_8+w_p1a                         #specific enthalpy in kJ/k
steam=IAPWS95(P=0.050, h=h_9)         #pressure p_8 in Mpa and specific enthalpy h_8 in kJ/kg
print(steam.T,steam.u,steam.x)        #Temperature T_8 in K, Internal energy u_8 in kJ/kg, quality its value is false
print(steam.v,steam.s)                #specific volume v_8 in m^3/kg and Entropy s_8 in kJ/kg*k
#state 10, Fixed parameter p,s
steam=IAPWS95(P=0.102, s=0.6963006155511)  #Becuase of constant entropy and given pressure p_8s in Mpa and s_10s=s_9 in kJ/kg*k
print(steam.h,steam.u)                     #specific enthalpy h_10s in kJ/kg, specific internal energy u_10s kJ/kg.
print(steam.v, steam.x,steam.T)            #specific volume v_10s,qaulity x_10s its value is false, and Temperature T_10sin K
#state 10, Fixed parameter p,h
h_10s=207.0084361838
w_p2s=h_10s-h_9                 #specific work done by fourth stage turbine  ideal in kJ/kg
w_p2a=w_p2s/effi                #specific work done by fourth stage turbine  ide in kJ/kg
h_10=h_9+w_p2a                  #specific enthalpy in kJ/k
steam=IAPWS95(P=0.102, h=h_10)  #pressure p_8 in Mpa and specific enthalpy h_8 in kJ/kg
```

```
steam=IAPWS95(P=0.102, h=h_10)     #pressure p_8 in Mpa and specific enthalpy h_8 in kJ/kg
print(steam.T,steam.u)             #specific enthalpy h_10s in kJ/kg, specific internal energy u_10s kJ/kg.
print(steam.v, steam.x,steam.s)    #specific volume v_10s,qaulity x_10s its value is false, and Temperature T_10sin K
#state 11s, Fixed parameter p,s
steam=IAPWS95(P=0.260, s=0.6963294003860)  #Becuase of constant entropy and given pressure p_8s in Mpa and s_10s=s_9 in kJ/kg*k
print(steam.h,steam.u)                     #specific enthalpy h_10s in kJ/kg, specific internal energy u_10s kJ/kg.
print(steam.v, steam.x,steam.T)            #specific volume v_10s,qaulity x_10s its value is false, and Temperature T_10sin K
#state 11, Fixed parameter p,h
h_11s=207.1775875181763           #specific enthalpy in kJ/k
w_p3s=h_11s-h_10                  #specific work done by fourth stage turbine  ideal in kJ/kg
w_p3a=w_p3s/effi                  #specific work done by fourth stage turbine  ide in kJ/kg
h_11=h_10+w_p3a                   #specific enthalpy in kJ/k                  #specific work done by fourth stage turbine  i
liquid=IAPWS95(P=0.260, h=h_11)   #pressure p_8 in Mpa and specific enthalpy h_8 in kJ/kg
print(liquid.T,liquid.u)          #specific enthalpy h_10s in kJ/kg, specific internal energy u_10s kJ/kg.
print(liquid.v, liquid.x,liquid.s) #specific volume v_10s,qaulity x_10s its value is false, and Temperature T_10sin K
#state 12, heat exchanger
liquid=IAPWS95(P=0.260, T=361.3433)   #pressure developed by pump 3 in MPa and Temperature is saturated temperature of p=260kpa
print(liquid.s,liquid.u)               #specific enthalpy h_10s in kJ/kg, specific internal energy u_10s kJ/kg.
print(liquid.v, liquid.x,liquid.h)     #specific volume v_12,qaulity x_12 its value is false, and Entropy s_12 in kJ/kg*k
#state 13s, Fixed parameter P,s
liquid=IAPWS95(P=4, s=1.1717602088934165)
print(liquid.T,liquid.u,liquid.h)       #Temperature T_8 in K, Internal energy u_8 in kJ/kg, enthalpy h_8 in kJ/kg
print(liquid.v,liquid.x)                   #specific volume v_8 in m^3/kg and Entropy s_8 in kJ/kg*k
#state 13, Fixed parameter p,h
h_13s=373.4570747594243
```

```
liquid=IAPWS95(P=0.102, h=h_13)    #pressure p_8 in Mpa and specific enthalpy h_8 in kJ/kg
print(liquid.T,liquid.u)            #specific enthalpy h_10s in kJ/kg, specific internal energy u_10s kJ/kg.
print(liquid.v, liquid.x,liquid.s)   #specific volume v_10s,qaulity x_10s its value is false, and Temperature T_10sin K
#state 14, Fixed parameter p,saturated
sat_steam=IAPWS95(P=0.260, x=0)
print(sat_steam.T,sat_steam.u,sat_steam.h)       #Temperature T_8 in K, Internal energy u_8 in kJ/kg, enthalpy h_8 in kJ/kg
print(sat_steam.v,sat_steam.s)                   #specific volume v_8 in m^3/kg and Entropy s_8 in kJ/kg*k
#state 15, Fixed parameter p,h
h_14=540.87382089307243
h_15=h_14
steam=IAPWS95(P=0.102, h=h_15)     #pressure p_16 in Mpa and specific enthalpy h_16 in kJ/kg
print(steam.T,steam.u)             #specific enthalpy h_16s in kJ/kg, specific internal energy u_16 kJ/kg.
print(steam.v, steam.x,steam.s)    #specific volume v_16s,qaulity x_16s its value is false, and Temperature T_16sin K
dm_dt=47.25                        #mass flow rate of steam from literature review in kg/s
#state 16, fixed parameter p,saturated
sat_steam=IAPWS95(P=0.102, x=0)
print(sat_steam.T,sat_steam.u, sat_steam.h)
print(sat_steam.v,sat_steam.s)
#state 17, fixed paramete p,h
h_16=419.84290730747483
h_17=h_16
steam=IAPWS95(P=0.050, h=h_17)     #pressure p_16 in Mpa and specific enthalpy h_16 in kJ/kg
print(steam.T,steam.u)             #specific enthalpy h_16s in kJ/kg, specific internal energy u_16 kJ/kg.
print(steam.v, steam.x,steam.s)
work_of_turbine_ideal=w_1s+w_2s+w_3s+w_4s+w_5s
```

```
power_in_ideal=(dm_dt*work_net_of_ideal)
print ('Power out put of the plant in ideal  {:>.2f}  KW' .format(power_in_ideal))
power_in_ideal=(dm_dt*work_net_of_ideal)/1000
print ('Power out put of the plant in ideal  {:>.2f}  MW' .format(power_in_ideal))
work=w_1a+w_2a+w_3a+w_4a+w_5a
print('Total work done of the turbine     {:>.2f} kJ/kg'.format(work))
workrequired=w_p1a+w_p2a+w_p3a+w_p4a
worknet=work-workrequired
print('Net work wout put of the plant     {:>.2f} kJ/kg' .format(worknet))
qindot=h_1-h_16
eta=worknet/qindot
print('Thermal efficiency for  cycle      {:>.2f} %'.format(eta*100))
back_ratio=workrequired/work
print('Back work ratio                    {:>.2f} %'.format(back_ratio*100))
power=dm_dt*worknet
print('power out put of the plant         {:>.2f} kJ/S'.format(power))
Power=power
print('Power out put of the plant in MW   {:>.2f} KW' .format(Power))
Power=power/1000
print('Power out put of the plant in MW   {:>.2f} MW' .format(Power))
```

Figure A.8 Steam code in PYTHON

The calculation of solar assisted in PYTHON, this calculation done based on Rankine steam cycle. The following Figure A.9 shows all the mathematical procedure.

```
# -*- coding: utf-8 -*-
"""
Created on Wed Jul 17 15:05:28 2019

@author: REDWAN ALI USMAN
thesis title feasibility study of solar assisted waste to energy power plant for Adama city python code for steam cycle.
"""
from iapws import IAPWS95
from numpy import *
#state 1,  Fixed parameter P,T
steam=IAPWS95(P=4, h=1731.161)       #This value come from calorific value of waste. enthalpy from waste thermal h_1 in KJ/kg and pressur
e P_1 in Mpa
print(steam.v,steam.x,steam.s)       #By using the above value we gate volume v_1 in m^/kg and quality x_1 is dimension less and entropy
 s_1 in kJ/kg*k
print(steam.T,steam.u)               #Temperature T_1 in K and Internal Energy u_1 in kJ/kg
#state 2s, Fixed parameter P,s
steam=IAPWS95(P=0.618, s=4.0263024)  #Becuase of constant entropy and given pressure p_2s in Mpa and s_2s=s_1 in kJ/kg*k
print(steam.h,steam.u)               #specific enthalpy h_2s in kJ/kg, specific internal energy u_2s kJ/kg.
print(steam.v, steam.x,steam.T)      #specific volume v_2s,qaulity x_2s its value is false, and Temperature T_2sin K
h_1=1731.161                         #specific enthalpy in kJ/kg
h_2s=1578.0149969                    #specific enthalpy in kJ/kg
w_1s=h_1-h_2s                        #specific work done in turbine one ideal in kJ/kg
effi=0.85                            #efficiency of turbine
w_1a=effi*w_1s                       #specific work done in turbine one in actual kJ/kg
print(w_1a)                          #specific work in turbine one in actual kJ/kg
h_2=h_1- w_1a                        #specific enthalpy in kJ/kg
print (h_2 )                         #specific enthalpy in kJ/kg
#state 2, Fixed parameter p,h
steam=IAPWS95(P=0.618, h=h_2)        #pressure p_2 in Mpa and specific enthalpy h_2 in kJ/kg
print(steam.T,steam.u,steam.x)       #Temperature T_2 in K, Internal energy u_2 in kJ/kg, quality
print(steam.v,steam.s)               #specific volume v_2 in m^3/kg and Entropy s_2 in kJ/kg*k
#state 3, Fixed parameter p,T reheated
steam=IAPWS95(P=0.618, T=523.50404528)   #Reheated and Temperature T_3 back to its initial point with constant pressure P_3
print(steam.v,steam.x,steam.s)           #specific volume v_3,quality its value is false, and Entropy
print(steam.h,steam.u)                   #specific enthalpy h_3, and Enternal energy u_3 in kJ/kg
#state 4s, Fixed parameter p,s
steam=IAPWS95(P=0.260, s=7.17010937811)    #Becuase of constant entropy and given pressure p_4s in Mpa and s_4s=s_3 in kJ/kg*k
print(steam.h,steam.u)                     #specific enthalpy h_4s in kJ/kg, specific internal energy u_4s kJ/kg.
print(steam.v, steam.x,steam.T)            #specific volume v_4s,qaulity x_4s its value is false, and Temperature T_4sin K
#state 4, Fixed parameter p,h
h_4s=2772.4451119                          #specific enthalpy in kJ/kg
h_3=2957.664024                            #specific enthalpy in kJ/kg
w_2s=h_3-h_4s                              #specific work done by first stage turbine  ideal in kJ/kg
w_2a=effi*w_2s                             #specific work done by fist state turbine  actual in kJ/kg
h_4=h_3-w_2a                               #specific enthalpy in kJ/kg
steam=IAPWS95(P=0.260, h=h_4)              #pressure p_4 in Mpa and specific enthalpy h_4 in kJ/kg
print(steam.T,steam.u,steam.x)             #Temperature T_4 in K, Internal energy u_4 in kJ/kg, quality its value is false
print(steam.v,steam.s)                     #specific volume v_4 in m^3/kg and Entropy s_4 in kJ/kg*k
```

```
#state 5, Fixed parameter p,h
h_5s=2631.770537                    #specific enthalpy in kJ/kg
w_3s=h_4-h_5s                       #specific work done by second stage turbine  ideal in kJ/kg
w_3a=effi*w_3s                      #specific work done by second stage turbine  ideal in kJ/kg
h_5=h_4-w_3a                        #specific enthalpy in kJ/kg
steam=IAPWS95(P=0.102, h=h_5)       #pressure p_5 in Mpa and specific enthalpy h_5 in kJ/kg
print(steam.T,steam.u,steam.x)      #Temperature T_5 in K, Internal energy u_5 in kJ/kg, quality its value is false
print(steam.v,steam.s)              #specific volume v_5 in m^3/kg and Entropy s_5 in kJ/kg*k
#state 6s, Fixed parameter p,s
steam=IAPWS95(P=0.050, s=7.30188041) #Becuase of constant entropy and given pressure p_6s in Mpa and s_6s=s_5 in kJ/kg*k
print(steam.h,steam.u)              #specific enthalpy h_6s in kJ/kg, specific internal energy u_6s kJ/kg.
print(steam.v, steam.x,steam.T)     #specific volume v_6s,qaulity x_6s its value is false, and Temperature T_6sin K
#state 6, Fixed parameter p,h
h_6s=2542.0226404                   #specific enthalpy in kJ/kg
w_4s=h_5-h_6s                       #specific work done by fourth stage turbine  ideal in kJ/kg
w_4a=effi*w_4s                      #specific work done by fourth stage turbine  ide in kJ/kg
h_6=h_5-w_4a                        #specific enthalpy in kJ/kg
steam=IAPWS95(P=0.050, h=h_6)       #pressure p_6 in Mpa and specific enthalpy h_6 in kJ/kg
print(steam.T,steam.u,steam.x)      #Temperature T_6 in K, Internal energy u_6 in kJ/kg, quality its value is false
print(steam.v,steam.s)              #specific volume v_6 in m^3/kg and Entropy s_6 in kJ/kg*k
#state 7s, Fixed parameter p,s
steam=IAPWS95(P=0.012, s=7.350552194) #Becuase of constant entropy and given pressure p_7s in Mpa and s_7s=s_5 in kJ/kg*k
print(steam.h,steam.u)              #specific enthalpy h_7s in kJ/kg, specific internal energy u_7s kJ/kg.
print(steam.v, steam.x,steam.T)     #specific volume v_7s,qaulity x_7s its value is false, and Temperature T_7sin K
#state 7 Fixed parameter p,h
h_7s=2369.8435890                   #specific enthalpy in kJ/kg
w_5s=h_6-h_7s                       #specific work done by fourth stage turbine  ideal in kJ/kg
w_5a=effi*w_5s                      #specific work done by fourth stage turbine  ide in kJ/kg
h_7=h_6-w_5a                        #specific enthalpy in kJ/k
steam=IAPWS95(P=0.012, h=h_7)       #pressure p_7 in Mpa and specific enthalpy h_7 in kJ/kg
print(steam.T,steam.u,steam.x)      #Temperature T_7 in K, Internal energy u_7 in kJ/kg, quality its value is false
print(steam.v,steam.s)              #specific volume v_7 in m^3/kg and Entropy s_7 in kJ/kg*k
#state 8, Fixed parameter p,saturated
sat_steam=IAPWS95(P=0.012, x=0)
print(sat_steam.T,sat_steam.u,sat_steam.h)      #Temperature T_8 in K, Internal energy u_8 in kJ/kg, enthalpy h_8 in kJ/kg
print(sat_steam.v,sat_steam.s)                  #specific volume v_8 in m^3/kg and Entropy s_8 in kJ/kg*k
#state 9s, Fixed parameter p,s
steam=IAPWS95(P=0.050, s=0.696279580)  #Becuase of constant entropy and given pressure p_8s in Mpa and s_8s=s_7 in kJ/kg*k
print(steam.h,steam.u)                 #specific enthalpy h_8s in kJ/kg, specific internal energy u_8s kJ/kg.
print(steam.v, steam.x,steam.T)        #specific volume v_8s,qaulity x_8s its value is false, and Temperature T_8sin K
```

```
#state 9, Fixed parameter p,h
h_9s=206.94903427                   #specific enthalpy in kJ/kg
h_8=206.91058331                    #specific enthalpy in kJ/kg
w_p1s=h_9s-h_8                      #specific work required for pump one in ideal in kJ/kg
w_p1a=w_p1s/effi                    #specific work required for pump one in real in kJ/kg
h_9=h_8+w_p1a                       #specific enthalpy in kJ/k
steam=IAPWS95(P=0.050, h=h_9)       #pressure p_9 in Mpa and specific enthalpy h_9 in kJ/kg
print(steam.T,steam.u,steam.x)      #Temperature T_9in K, Internal energy u_9 in kJ/kg, quality its value is false
print(steam.v,steam.s)              #specific volume v_9 in m^3/kg and Entropy s_9 in kJ/kg*k
#state 10, Fixed parameter p,s
steam=IAPWS95(P=0.102, s=0.6963006155511)  #Becuase of constant entropy and given pressure p_10s in Mpa and s_10s=s_9 in kJ/kg*k
print(steam.h,steam.u)                     #specific enthalpy h_10s in kJ/kg, specific internal energy u_10s kJ/kg.
print(steam.v, steam.x,steam.T)            #specific volume v_10s,qaulity x_10s its value is false, and Temperature T_10sin K
#state 10, Fixed parameter p,h
h_10s=207.0084361838                #specific enthalpy in kJ/kg
w_p2s=h_10s-h_9                     #specific work required for pump two in ideal in kJ/kg
w_p2a=w_p2s/effi                    #specific work required for pump two in real in kJ/kg
h_10=h_9+w_p2a                      #specific enthalpy in kJ/k
steam=IAPWS95(P=0.102, h=h_10)      #pressure p_10 in Mpa and specific enthalpy h_10 in kJ/kg
print(steam.T,steam.u)              #Temperature T_10 in K, specific internal energy u_10 kJ/kg.
print(steam.v, steam.x,steam.s)     #specific volume v_10,qaulity x_10 its value is false, and specific enthropy s_10 in KJ/kg
#state 11s, Fixed parameter p,s
steam=IAPWS95(P=0.260, s=0.6963294003860)  #Becuase of constant entropy and given pressure p_8s in Mpa and s_11s=s_10 in kJ/kg*k
print(steam.h,steam.u)                     #specific enthalpy h_11s in kJ/kg, specific internal energy u_10s kJ/kg.
print(steam.v, steam.x,steam.T)            #specific volume v_11s,qaulity x_11s its value is false, and Temperature T_11sin K
#state 11, Fixed parameter p,h
h_11s=207.1775875181763             #specific enthalpy in kJ/k
w_p3s=h_11s-h_10                    #specific work required for pump three in ideal in kJ/kg
w_p3a=w_p3s/effi                    #specific work required for pump three in real in kJ/kg
h_11=h_10+w_p3a                     #specific enthalpy in kJ/k
liquid=IAPWS95(P=0.260, h=h_11)     #pressure p_11 in Mpa and specific enthalpy h_11 in kJ/kg
print(liquid.T,liquid.u)            # Temperature T_11 in Kin kJ/kg, specific internal energy u_11 kJ/kg.
print(liquid.v, liquid.x,liquid.s) #specific volume v_11,qaulity x_11 its value is false, and specific enthropy s_11 in KJ/kg
#state 12, heat exchanger
liquid=IAPWS95(P=0.260, T=361.3433)     #pressure p_12 in Mpa and Temperature calculated from heat exchange T_12
print(liquid.s,liquid.u)                #Entropy s_12 in kJ/kg*kin , specific internal energy u_12 kJ/kg.
print(liquid.v, liquid.x,liquid.h)      #specific volume v_12,qaulity x_12 its value is false, and specific enthalpy h_12
#state 13s, Fixed parameter P,s
liquid=IAPWS95(P=4, s=1.1717602088934165)   #Becuase of constant entropy and given pressure p_13s in Mpa and s_13s=s_12 in kJ/kg*k
print(liquid.T,liquid.u,liquid.h)           #Temperature T_13 in K,specific Internal energy u_13 in kJ/kg, enthalpy h_13 in kJ/kg
print(liquid.v,liquid.x)                    #specific volume v_13 in m^3/kg and qaulity s_13 in kJ/kg*k
#state 13, Fixed parameter p,h
h_13s=373.4570747594243                     #specific enthalpy in kJ/k
h_12=369.59089376842911                     #specific enthalpy in kJ/k
w_p4s=h_13s-h_12                            #specific work required for pump four in ideal in kJ/kg
w_p4a=w_p4s/effi                            #specific work required for pump four in ideal in kJ/kg
h_13=h_12+w_p4a                             #specific enthalpy in kJ/k
liquid=IAPWS95(P=4, h=h_13)                 #pressure p_13 in Mpa and specific enthalpy h_8 in kJ/kg
print(liquid.T,liquid.u)                    #specific enthalpy h_10s in kJ/kg, specific internal energy u_10s kJ/kg.
print(liquid.v, liquid.x,liquid.s)          #specific volume v_10s,qaulity x_10s its value is false, and Temperature T_10sin K
```

```
#state 14, Fixed parameter p,saturated
sat_steam=IAPWS95(P=0.260, x=0)              #pressure p_14 in Mpa and qaulity x=0, which is saturated state
print(sat_steam.T,sat_steam.u,sat_steam.h)   #Temperature T_14 in K,specific Internal energy u_14 in kJ/kg,specific enthalpy h_14 in
 kJ/kg
print(sat_steam.v,sat_steam.s)               #specific volume v_14 in m^3/kg and Entropy s_14 in kJ/kg*k
#state 15, Fixed parameter p,h
h_14=540.87382089307243          #specific enthalpy in kJ/k
h_15=h_14                        #specific enthalpy in kJ/k
steam=IAPWS95(P=0.102, h=h_15)   #pressure p_16 in Mpa and specific enthalpy h_16 in kJ/kg
print(steam.T,steam.u)           #specific enthalpy h_16s in kJ/kg, specific internal energy u_16 kJ/kg.
print(steam.v, steam.x,steam.s)  #specific volume v_16s,qaulity x_16s its value is false, and Temperature T_16sin K
dm_dt=47.25                      #mass flow rate of steam from literature review in kg/s
#state 16, fixed parameter p,saturated
sat_steam=IAPWS95(P=0.102, x=0)           #pressure p_16 in Mpa and qaulity x=0, which is saturated state
print(sat_steam.T,sat_steam.u, sat_steam.h) #Temperature T_16 in K,specific Internal energy u_16 in kJ/kg,specific enthalpy h_16 in kJ/kg
print(sat_steam.v,sat_steam.s)            #specific volume v_16 in m^3/kg and Entropy s_16 in kJ/kg*k
#state 17, fixed paramete p,h
h_16=419.84290730747483          #specific enthalpy in kJ/k
h_17=h_16                        #specific enthalpy in kJ/k
steam=IAPWS95(P=0.050, h=h_17)   #pressure p_16 in Mpa and specific enthalpy h_16 in kJ/kg
print(steam.T,steam.u)           #Temperature T_17 in K and specific internal energy u_17
print(steam.v, steam.x,steam.s)  #specific volume, quality x_17,and sepcific enthropy s_17
work_of_turbine_ideal=w_1s+w_2s+w_3s+w_4s+w_5s
print('Total work done of the turbine in ideal {:>.2f} kJ/kg' .format(work_of_turbine_ideal))
work_of_pump_ideal=w_p1s+w_p2s+w_p3s+w_p4s
print('Total work required for pump in ideal {:>.2f} kJ/kg'.format(work_of_pump_ideal) )
work_net_of_ideal=work_of_turbine_ideal-work_of_pump_ideal
print('Net work wout put of the palnt in ideal  {:>.2f} kJ/kg'.format(work_net_of_ideal) )
power_in_ideal=(dm_dt*work_net_of_ideal)
print ('Power out put of the plant in ideal  {:>.2f}  KW' .format(power_in_ideal))
power_in_ideal=(dm_dt*work_net_of_ideal)/1000
print ('Power out put of the plant in ideal  {:>.2f}  MW' .format(power_in_ideal))
work=w_1a+w_2a+w_3a+w_4a+w_5a
print('Total work done of the turbine     {:>.2f} kJ/kg'.format(work))
workrequired=w_p1a+w_p2a+w_p3a+w_p4a
worknet=work-workrequired
print('Net work wout put of the plant     {:>.2f} kJ/kg' .format(worknet))
qindot=h_1-h_16
eta=worknet/qindot
print('Thermal efficiency for  cycle      {:>.2f} %'.format(eta*100))
back_ratio=workrequired/work
print('Back work ratio                    {:>.2f} %'.format(back_ratio*100))
power=dm_dt*worknet
print('power out put of the plant         {:>.2f} kJ/S'.format(power))
Power=power
print('Power out put of the plant in MW   {:>.2f} KW' .format(Power))
Power=power/1000
print('Power out put of the plant in MW   {:>.2f} MW' .format(Power))
```

Figure A. 9 steam cycle code in Python

The isentropic efficiency ($\eta_{T,Hp}$), for the HP turbine is pre-determined to 0.8 and the efficiency,($\eta_{L,Lp}$), for the Lp turbine is calculated.

$$\eta T, Lp = \frac{h4-h7}{h4-h7is} \tag{1}$$

The pre-determined node 7 determines the efficiency for the whole LP turbine.

Feed water tank

The feed water tank gathers the water before it goes in to the steam boiler. The conditions for the tank are calculated with the equations below.

$$h17 * \frac{dm17}{dt} = h24 * \frac{dm24}{dt} + h30 * \frac{dm30}{dt} \tag{2}$$

$$h17 = \frac{h24*\frac{dm24}{dt}+h30*\frac{dm30}{dt}}{\frac{dm24}{dt}+\frac{dm30}{dt}} \tag{3}$$

Two stage DH heat exchanger

the two predetermined steps of heating of the DH- water leads to a calculable difference between the two steps. This difference correlates with the difference of needed mass flow in the two steps. The mass flow in node 7 varies in the model.

$$Difference, D = \frac{h11-h12}{h7-h13} \tag{4}$$

$$\frac{dm}{dt11} = D * \frac{dm7}{dt} \tag{5}$$

Condensate tank

in the condensate tank the condensate from the two DH- condensers and the second preheater condenser gather. The conditions for the condensate tank are calculated below.

$$h14 * \frac{dm14}{dt} = h12 * \frac{dm12}{dt} + h15 * \frac{dm15}{dt} + h10 * \frac{dm10}{dt} \tag{6}$$

$$h10 = h14 \tag{7}$$

$$\frac{dm14}{dt} = \frac{dm12}{dt} + \frac{dm15}{dt} + \frac{dm10}{dt} \tag{8}$$

$$h14 = \frac{h12*\frac{dm12}{dt}+h15*\frac{dm15}{dt}}{\frac{dm15}{dt}+\frac{dm15}{dt}} \tag{9}$$

Pre heating of head water

The two different preheating steps of the feed water are designed to contribute for the half of the preheating each. The second steps characteristic is determined by the LP-turbine drain to the warm DH-condenser. The model varies the pressure for the first step of the preheating step and the available mass flow for the preheating steps.

$$h5 * \frac{dm5}{dt} = h9 * \frac{dm9}{dt} \quad (10)$$

Energy and mass balance or conservation

The two main physical relations that are used in the Matlab and python model are mass balance and energy balance. The sum of energy flow into one node is equal to the sum of energy flow out of it, and the same applies to the mass flow.

P=power=w (11)

h=enthalpy= kJ/kg

dm/dt=mass flow= kg/s

$$pin = hin * \frac{dmin}{dt} = hout * \frac{dmout}{dt} = pout \quad (13)$$

The conservation of mass and energy is used in three nodes and the calculations are displayed below.

$$h28 * \frac{dm28}{dt} = h9 * \frac{dm9}{dt} - h10 * \frac{dm10}{dt} + h15 * \frac{dm16}{dt} \quad (14)$$

$$h28 = \frac{h9*\frac{dm9}{dt} - h10*\frac{dm10}{dt} + h16*\frac{dm16}{dt}}{\frac{dm28}{dt}} \quad (15)$$

$$h30 * \frac{dm30}{dt} = h5 * \frac{dm5}{dt} + h29 * \frac{dm29}{dt} + h24 * dm24/dt \quad (16)$$

$$h24 = h30 \quad (17)$$

$$\frac{dm5}{dt} = \frac{dm30}{dt} \quad (18)$$

$$h30 = \frac{h5*\frac{dm5}{dt} + h29*\frac{dm29}{dt}}{\frac{dm5}{dt} + \frac{dm24}{dt}} \quad (19)$$

$$h30 * \frac{dm30}{dt} = h5 * \frac{dm5}{dt} + h29 * \frac{dm29}{dt} + h24 * \frac{dm24}{dt} \quad (20)$$

Energy outtake

The theoretical/estimations/calculations in the Matlab and python model are based on the equations below.

Enthalpy change

Every energy outtake in the steam cycle can be explained as an enthalpy outtake charge compared to the total enthalpy input change.

Outtake in node 5 $O5 = \frac{(h4-h5)+(h1-h3)}{(h1-h18)+(h4-h3)}$ (19)

$$O6 = \frac{(h4-h6)+(h1-h3)}{(h1-h18)+(h4-h3)} \quad (20)$$

$$O7 = \frac{(h4-h7)+(h1-h3)}{(h1-h18)+(h4-h3)} \quad (21)$$

$$O12 = \frac{(h7-h13)}{(h1-h18)+(h4-h3)} \quad (22)$$

Outtake fraction

The efficiency of every node depends on the energy outtake and the mass flow.

Outtake fraction in node 5=Ofs=Os*dms/dt

$$OF6 = O6 * \frac{dm6}{dt} \quad (24)$$

$$OF7 = O7 * \frac{dm7}{dt} \quad (25)$$

$$OF12 = O12 * \frac{dm12}{dt} \quad (26)$$

Electrical and thermal efficiency

the electrical and thermal efficiency's are determined by the total outtake fraction.

Electrical efficiency= nel=(oFs+Of6+OF7)/m1 (27)

APPENDIX B

The program used for simulating elemental composition for hundred tons of waste has been obtained from Avfall Sverige. The results of the simulation done using the Donetsk data are shown in Table 3A1, Table 3A2, Table 3A3, and Table 3A4. Since the real waste composition is likely to have higher moisture content, the data from this simulation is only used for calculations of the highest theoretical heat generation.

Table 3A1: Elemental composition software result by Avfall Sverige

Category						
paper	7.50	weight %	**Negative result component**			
plastic CH	10.0	weight %	moisture content weight %	37		
plastic PVC	0.00	weight %	Ash Content weight %	24		
polymer(polyuretan)	0.00	weight %	**Elemental composition analysis**			
plastic flamsk	0.00	weight %	carbon weight % dry, excl ash	60	**Sparelement**	g/tone
Tra	1.40	weight %	hydrogen weight % dry, excl ash	8.5	copper(CU)	280.6
Tra CCA-imp	0.00	weight %	Oxygen weight % dry, excl ash	29	lead(Pb)	259.1
Sanitetprod	0.00	weight %	Nitrogen weight % dry, excl ash	1.9	mercury(Hg)	0.6
Taxtail nature	3.30	weight %	Sulfur weight %dry, excl ash	0.2	manganese(Mn)	12.6
Taxtail flamsk	0.40	weight %	**Halogens**		Nickel(Ni)	92.5
Gummi vulk	0.90	weight %	Chlorine weight %dry, excl ash	0.6	Titanium(Ti)	0
Lader	0.90	weight %	Fluorine g/tone dry	244	Vanadn(V)	1.1
Matay full	50.0	weight %	Bromine g/tone dry	4.1	Zink (Zn)	1050
Tradg avfall	0.00	weight %	**Ash Composition**	weight %ASHES	cobalt(Co)	1
Glass	9.40	weight %	Na2O	8.3	cadmium (Cd)	
metal	3.20	weight %	K2O	8.4		
Gips	0.00	weight %	CaO	39		
Elektr.skrot	0.00	weight %	MgO	6.1		
Badack	0.00	weight %	SiO2	21		
			Fe2O3	6.4		
Brannbart kommunalt avfail	12.7	weight %	Al2O3	6.6		
Kompostebart kommunait avfa	0.00	weight %	TiO2	0.2		
Brannbart verksamhetsavfall	0.00	weight %	MnO	0.3		
papper plast tra (PPT)	0.50	weight %	BaO	0.1		
Returtra	0.00	weight %	SnO	0		
Rotslam	0.00	weight %	P2O5	2.9		
Rester	0.00	weight %				
Vatten	0.00	weight %				
Egen def 3	0.00	weight %				
Egen def 4	0.00	weight %				