CHAPTER ONE

INTRODUCTION

1.1 Background

Many current energy policies promote research to enhance the utilization of renewable energy or alternative sources, in large part to help mitigate environmental problems and improve the national energy security of countries [1]. In the power industrial sectors, there several types of power generation currently employ with firing coal, natural gas, and fossil fuel as supplying fuels. The problems emerge from power generation, not only the energy resources depletion, but also produce the contaminations from the thermal wastes. In general, any kind of activity involves combustion process, which is most likely to produce carbon dioxide, ozone and other unburned gasses and thus contributes to the greenhouse gases. In the current energy resources usage, such as fossil fuel, coal, and natural gas are primary energy resources for power generation.

Figure 1.1 graphically shows the different sharing of energy resources in producing power, and the coal, oil, and natural gas are most utilized as supplying fuels. However, the bio-fuel and waste still have not attracted attention to utilize in the power industrial sectors in the past few years. In the present time, there are many researches and practical experiences reveal cogeneration systems are the most appropriate option to install because its capability to provide both economic and environmental friendly [2].

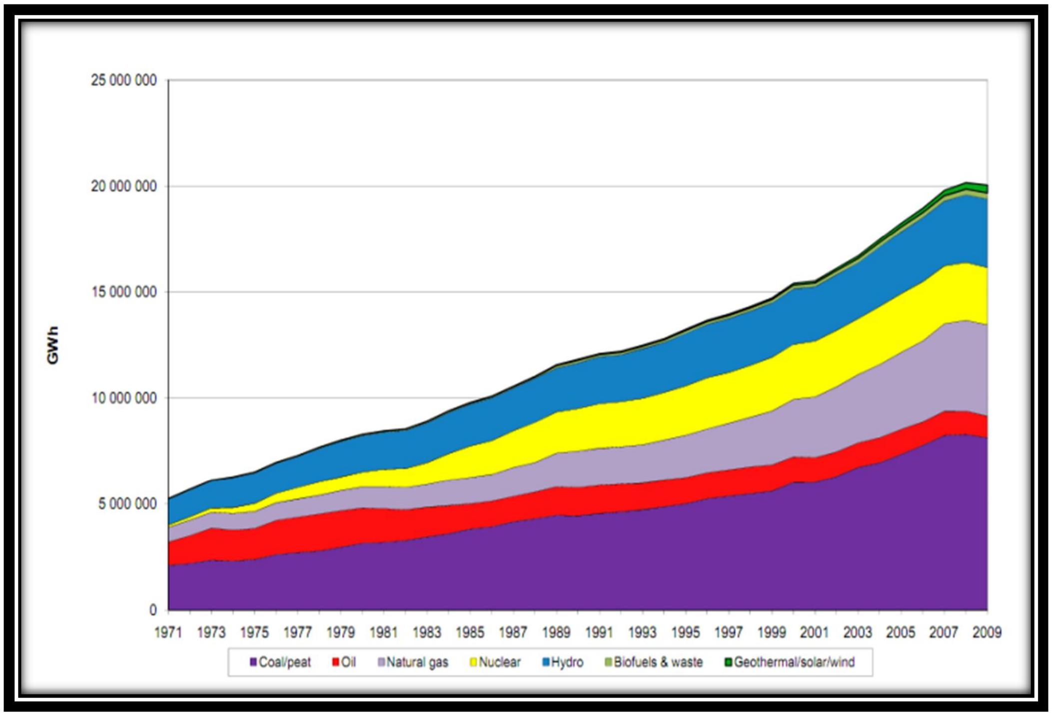

Figure 1.1 Electricity generations by fuels 2009 [2]

In thermal power plants, steam boiler is a device which can be run on solid fuel like fire wood, coal, bagasse, etc. Analysis has shown that some of agricultural residues have high percentages of hydrocarbons and can be used to fire boilers. If we utilize the available energy out of these wastes, the problem of solid waste disposal will not only be solved but also a significant amount of power will be generated for industrial and farm use.

In sugar industries, all of the electric power is generated using bagasse which is used to run the plant. This system was developed when the possibility of export of power to grid was not envisaged and the storage of large quantity of combustible bagasse in the premises of the sugar factory was not an advisable option bagasse is currently one of the popular options [3]. Also due to the high prices of energy and the decreasing fossil fuel recourses, the optimum application of energy and the energy consumption management methods are very important. This, in fact, requires accurate thermodynamic analysis of thermal systems for design and optimization purposes. In this regard, there are two essential tools available, such as energy analysis (referring to the first law of thermodynamic analysis) and exergy analysis (referring to the second law of thermodynamic analysis) [4]; The first law of thermodynamics states that when looking at the system and surroundings together, the total amount of energy will remain constant. The first law treats the different forms of energy as equivalent and does not distinguish the difference in quality between, among others, mechanical and thermal energy. Exergy analysis based on the first and second thermodynamic laws is a significant tool to analyze the energy systems. It also reveals the inefficient thermodynamic processes [4, 5, 6].

An inadequate understanding of energy and exergy analyses in the food industry and their low level of applicability lead to significant energy losses for enterprises. For this reason, energy losses should be minimized. Energy and exergy analyses of food processes make a major contribution to business profitability. In the food industry, energy consumption is very high due to the extensive use of energy in the manufacturing process. Since, the production of the sugar process needs steam energy [7].

In Sudan we have many sugar factories use bagasse as fuels, Elgunied is one of these factories, it had been built in elgazira state in 1962. The fiber in the cane is generally sufficient to enable the bagasse produced by the mills to supply all the steam necessary for power production and for manufacture, when utilized as fuel in the boiler furnaces. In this study, the energy and exergy analyses of processes would be calculated to get high energy efficiency according to design parameters for the elgunied sugar factory.

1.2 Problem statement

In recent years the entire world is aware about energy resources limitation, specifically Sudan country overcomes critical situation in energy resources. In sugar factories most of electricity energy product from burned bagasse one of these factories Elgunied sugar factory. Energy and Exergy analysis in the light of first law and second law of thermodynamics respectively require evaluating flow energy and exergy destruction of each part; to determine the parts have major contribute in exergy destruction.

1.3 Objectives of the research

The objective of this study is to carry out:

- An extensive energy (first law).
- Exergy (second law) analysis of the performance Elgunied sugar factory to identify the potential for improvement.
- To calculate exergy destruction of each component of elgunied sugar factory.
- The effect of throttle steam pressure and temperature, and effect of number of feedwater heaters, both in a qualitative and quantitative sense will be discussed.
- The results of analyses using both the first and second law of thermodynamics for the turbine cycle of the plant operating.

1.4 Scope

Calculate energy and exergy destruction to main equipment (boilers, steam turbine, mills, de superheaters, due to escape of flue gases over ambient and condenser).

1.5 Significance of Research

Exergy analysis which may be considered as accounting of the use of energy and material resources provide information on how effective a process takes place towards conserving natural resources. exergy analysis brings new to the system design, analysis, assessment, and improvement of energy systems. It also presents how efficiencies are defined for performance assessment. Case studies are given to explain how system exergy analysis is performed, and its efficiencies are evaluated for comparison. Exergy destruction rates for each component of the systems are also studied and presented to investigate the possibilities for determining the magnitudes and improving the performance.

1.6 Thesis outline

The general outline of the thesis is as follows:

- **Chapter 1**: Presents the general background, problem statements, the purpose and significance of study.
- **Chapter 2**: To study the relevant literature reviews and practical studies which are related in this thesis?
- **Chapter 3:** Describes the details of elgunied sugar factory's configurations and its components, which involve in this study based on firing bagasse and provides the

methodologies and assumptions utilized in the analysis. All the required data and fuels composition present in this chapter.

- **Chapter 4:** Description of the study results and discussions from the analysis which includes analysis of parametric studies.
- **Chapter5:** To summary the result and conclusion, findings and provide the further recommendations for the future work, including suggestions of possible improvement of cogeneration systems.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Both global and national energy polices promote research to increase the use of biomass-derived fuels, especially in Latin America, where energy from biomass is as much as 20% of the demand. In this framework sugarcane and its harvesting residues have the potential to produce first and second generation biofuels through both: biological and thermochemical conversion route [8]. Among renewable energy sources Biomass (e.g. paper, agriculture and forestry residues, straw, wood wastes, sawdust, paddy husk) is currently one of the most popular options [1]. In existing system in the sugar factories the steam is generated in the low-pressure boilers by burning all the bagasse generated; so that many researchers are developing technologies based on the energy potential of bagasse. Bagasse is the pulp remaining after the extraction of juice from sugar cane or similar plants: used as fuel an d for making paper.

The captive power for the sugar plant is generated from steam turbines from the sugar factory process steam. This is cogeneration of power. There is capacity of the sugar plant to generate surplus power to be used as captive power for by products or to be sold to the electricity grid. The motive power where variable speed drive is required for example cane preparatory devices, mills, ID and FD fans, boiler feed pump, injection pumps …etc is generally driven by mechanical drive steam turbines, the turbines which drives the variable or fluctuating loads like cane preparatory devices, mills are driven by steam turbines having governor of high speed droop (torque –speed characteristic) of about 10- 20%. For these reasons mentioned above and the other we have to calculate flow energy and exergy analyses to conserve the energy and the amounts of bagasse from wasted also to determine the maximum power and maximum exergy destruction and its position.

2.2 Current Studies of Bagasse

Many studies conducted to investigate the effect of the energy and exergy analysis, energy and exergy efficiency [9, 10], and exergy destruction. Until recently all of these attempts were based on the first law analysis and limited by economic and/or technical considerations, recently, the adequacy of the methodology was challenged by the use of the exergy concept based on the second law of thermodynamics, used the exergy analysis concept to calculate and provide a detailed breakdown of the sources of inefficiency of a combined cycle, also to evaluate the total efficiencies and to assess the thermodynamic losses [1]. They used exergy analysis of a heat-matched bagasse-based cogeneration plant of a typical sugar factory [3]; also they evaluate the total efficiencies of the factory and to identify and assess the thermodynamic losses, finally they found that the least efficient of component in the boiler and the most efficient component of plant in the turbine [11]. They analyzed the system components separately and to identify and quantify the sites which having the largest energy and exergy losses and they calculated the energy and exergy efficiency with different loads (60% & 100%) [4]. He presented and analyzed the energy and exergy of al Hussein power plant in Jordan, and he calculated largest energy and exergy losses of the various component of the plant [5]. Also he calculated the total exergy destruction of the plant finally he found that the largest one in the boiler system (77%). Carried out a comparison between the various energy losses and exergy destruction, The energetic input, energetic output, exergetic input, exergetic output of the power plant and he found that the maximum rate of exergy destruction has been in the boiler than any other components [6, 12]. And there is a significant reduction in the rate of exergy destruction under different turbine loads (100%, 80% and 60%).

Low efficiency mill turbines was to be replaced with hydraulic drives and DC motors, thus they found that it caused to be increased in sugar mill and aided of power to grid [15].

2.2.1 Bagasse Feeder

Sugar cane is the raw material for unrefined sugar production. The cane is crushed in a mill which extracts the juice with efficiencies ranging between 55 and 70%. The milling residue, called bagasse, has moisture content between 40 and 50%. For this reason, many producers dry the bagasse in atmospheric conditions before using it as fuel [16].

The fiber in the cane is generally sufficient to enable the bagasse produced by the mills to supply all the steam necessary for power production and for manufacture, when utilized as fuel in the boiler furnaces. And it’s traveled by a chain conveyor with slate (2200 x 800 mm^2), used to transfer the bagasse to bagasse spreading box, to spread it into boiler house. The amount of bagasse can be controlled by controlling the speed of the conveyor. There are two more types of bagasse feeder [16]:

I- Revolving cylinder feeder.

II- Screw conveyor feeder.

2.2.2 Excess Air for Combustion of Bagasse

If only theoretical air is supplied in industrial boiler for combustion of bagasse, then possibility of incomplete combustion may take place therefore carbon monoxide is formed instead of carbon dioxide, under the mill working conditions, the average values were taken as [15]:

1- Moisture content of bagasse (w) = 50 %

2- Sucrose in bagasse (s) = 35 %

$$\text{Excess air (m)} = \frac{\text{weight of actual air}}{\text{Weight of theoretical air}}$$

Air for combustion of dry bagasse = 5.728 kg /kg of dry bagasse

Actual air for combustion of wet bagasse =5.728 (1-w) kg

Theoretical air = 5.728 (1- 0.5) = 2.88 kg

If excess air is 0.35 then the actual air is 1.35

Then the actual air will be = 5.728 (1-0.5) * 1.35 = 3.888 kg.

2.2.3 Products of Bagasse Combustion

Inlet to the furnace is [16]:

i - Bagasse which contents of C, O_2, and H_2O as moisture

ii - Air for combustion which contents O_2 and N_2

Out of the furnace is:

i - $C + O_2 = CO_2$

ii - $2\,H_2 + O_2 \longrightarrow 2\,H_2O$ (water vapor) and also moisture of bagasse iii - Oxygen as excess air or oxygen which content in bagasse

iv - Nitrogen from air

Weight of bagasse + weight of air = weight of gas +weight of ash

But weight of ash is negligible

Weight of gas W_g = 5.76 (1-w) (m+1) kg / kg of bagasse

2.3 Quantity of Steam Obtainable From Unit Weight of Bagasse

In order to calculate the quantity of steam obtainable from unit weight of bagasse, following heat losses were considered in the furnace and at the boiler [14, 15].

2.3.1 Condensation heat loss (L_c)

Use of full heat equivalent to gross calorific value GCV in industrial boilers is not possible .Some amount of heat equivalent to latent heat of water evaporation of the combustion heat is used for evaporation of water formed by H_2 and presents in bagasse as moisture. This is condensation heat loss and is carried away or lost along with flue gas.

This heat loss can be calculated as heat difference between GCV and NCV.

L_c = GCV –NCV

If w = 50% and S =2%

$L_c = \{4600(1- w) – 1200S\} – \{4250 -1200S - 4850w\}$

$= \{4600(1- 0.5) - 1200\times0.02\} - \{4250 – 1200 \times0.02 – 4850 \times 0.5\}$

$= 457$ kcal/kg

2.3.2 Sensible Heat Loss (L_S)

This heat loss is proportional to the outlet temperature rise of flue gas from the last heat recovery unit of the boiler above the atmospheric temperature. The flue gas temperature varies from 330 C^0 to 370 C^0.The sensible heat loss is evaluated by considering the weight of each product of combustion and their specific heat and is given by the following equation.

$L_S = \{(1- w)\ (1.4m – 0.13) + 0.5\}\ \{T_g- T_a\}$ kcal/kg

T_g = Flue gas temperature.

T_a = Ambient temperature.

If w=50%, m =1.35, T_g =160 C^0 and T_a=30 C^0

$L_S = \{(1- 0.5)(1.4\times 1.35- 0.13) + 0.5\}\{160 -30\} = 179$ kcal/kg.

2.3.3 Loss of Heat Due To Incomplete Combustion (L_i)

This incomplete combustion loss may be due to insufficient capacity of FD fan or ID fan or lower combustion temperature.

Effect of bagasse drying on:

1- GCV.
2- NCV.
3- Bagasse weight.
4- Bagasse total heat.
5- Boiler efficiency.

Bagasse can be dried by flue gas heat, steam, solar heat etc

GCV and NCV increase with bagasse drying but bagasse weight reduces [16]:

GCV = 4600 (1- w) – 1200S

GCV1 =4600 (1-0.5) - 1200×0.02 = 2276 kcal/kg

GCV2 =4600(1-0.04) -1200×0.02 (1-0.5)/(1-0.4) = 2731.2 kcal/kg

Weight of bagasse after drying W_b = (1- 0.5)/(1-0.4) =0.833 kg

Total heat = GCV × W_b = 3721.2× 0.833 = 2276 kcal/kg, no change in total heat of bagasse.

NCV = 4250 – 1200S – 4850w

NCV1 = 4250-1200×0.02 - 4850×0.5 = 1801 kcal/kg

NCV2 = 4250- 1200×0.02 (1- 0.5)/(1-0.4)- 4850×0.4 =2281.2 kcal/kg

Total NCV heat = NCV × W_b = 2281.2 × 0.833 = 1901 kcal/kg

Boiler efficiency increase with reduction in bagasse moisture due to effect on increase in NCV

2.4 Boiler Heat Balance

Boiler Efficiency (η_b):

Boiler efficiency is the ratio of useful heat output to heat input as GCV

Heat output is the heat gained by water to form steam

Boiler efficiency = Heat output / Heat input

= {heat input – losses}/heat input

Heat losses = (L_C + L_S +L_U + L_r +L_I)

Where

L_U= Unburned bagasse loss

L_r= Radiation loss

Heat output = GCV - (L_C + L_S +L_U + L_r +L_I)

Heat output = {GCV - L_C} - {L_S +L_U + L_r +L_I}

Heat output = NCV - {L_S +L_U + L_r +L_I}

Heat output = {NCV – L_S} $\times\alpha\times\beta\times\gamma$

$\alpha\times\beta\times\gamma$ = Coeiffient of heat loss for un burnt bagasse ,radiation and incomplete combustion loss respectively

η_b = {[NCV – L_S] $\times\alpha\times\beta\times\gamma$/GCV} $\times$100

Where

α = Co-efficient representing heat loss due to unburnt solids. For spreader stroker furnaces, its normal value is taken as 0.975. β = Co-efficient to account for heat losses by radiation. This value varies from 0.95 to 0.99 for more or less efficient lagging. Its value is taken as 0.97.
γ = Co-efficient of incomplete combustion. Its value is taken as 0.95 [16].

2.5 Steam Turbines

The captive power for the sugar plant is generated from steam turbines from the sugar factory process steam. This is cogeneration of power. There is capacity of the sugar plant to generate surplus power to be used as captive power for by products or to be sold to the electricity grid.

2.5.1 Mechanical Drive Turbines and Electrical Drive Turbines

The motive power where variable speed drive is required for example cane preparatory devices, mills, ID and FD fans, boiler feed pump, injection pumps …etc is generally driven by mechanical drive steam turbines ,the turbines which drives the variable or fluctuating loads like cane preparatory devices, mills are driven by steam turbines having governor of high speed droop (torque –speed characteristic) of about 10- 20%.At high torque demand the droop is more and the power demand is maintained and ultimately the steam flow rate is regulated at boiler outlet. The lower droop is necessary fluctuation on boiler steam load. For constant torque requirement the steam turbines are having governors with 3to6 %droop are installed. The electrical drive or alternator drive steam turbines are also fairly constant speed governing type having droop in the range of 3 to 6% to maintain the frequency of the output electrical power.

2.5.2 Specific steam rate of the steam turbine

The specific steam rate is estimated from energy balance of heat inlet to the turbine, heat outlet in exhaust and motive energy output of the turbine. The motive energy output depends upon difference heat inlet to the steam turbine and heat outlet from exhaust of the turbine Energy output from the steam turbine in one hour = 1 kWH = 860 kcal = 3600 kJ[16].

1 hp = 632 kcal = 2650 kJ

1- Energy [heat] inlet to the steam turbine in one hour is given by:-

Weight of steam in kg/hr × enthalpy of steam in kcal/kg of steam

$= W_S \times H_1$ kcal

Where

W_S = weight of steam in kg

H_1 = enthalpy of steam in Kcal depending on the inlet steam pressure and temperature determined from steam table.

2 - Energy [heat] outlet from exhaust steam = $W_S \times H_2$

Where:

H_2 = enthalpy of steam depending on exhaust steam pressure

$860 = W_S \{H_1 - H_2\} \times \eta_g \times \eta_m \times \eta_a$

Where η_g, η_m and η_a are gearbox efficiency, mechanical efficiency and alternator efficiency respectively

$W_S = 860 / \{\{H_1 - H_2\} \times \eta_g \times \eta_m \times \eta_a\}$ in kg of steam / kWH

$W_S = 632 / \{\{H_1 - H_2\} \times \eta_g \times \eta_m \times \eta_a\}$ in kg of steam / HPH.

$W_S = 3600 / \{\{H_1 - H_2\} \times \eta_g \times \eta_m \times \eta_a\}$ in kg of steam / kWH where H_1 and H_2 in kJ/kg

2.6 Energy and Exergy

2.6.1 Definition of Energy and Exergy

Whether we realize it or not, energy is an important part of most aspects of daily life. The quality of life, and even its sustenance, depends on the availability of energy. Therefore, it is important to have a good understanding of the sources of energy, the conversion of energy from one form to another and the ramifications of these conversions. Energy exists in numerous forms such as thermal, mechanical, electric, chemical, and nuclear. Even mass can be considered a form of energy.

From the thermodynamic point of view, exergy is defined as the maximum amount of work which can be produced by a system or a flow of matter or energy as it comes to equilibrium with a reference environment. Rather exergy is consumed or destroyed, due to irreversibilities in any real process. The exergy consumption during a process is proportional to the entropy created due to irreversibilities associated with the process [10].

2.6.2 The reference point

Exergy is always evaluated with respect to a reference environment. The reference environment is in stable equilibrium, acts as an infinite system and is a sink or source for heat and materials. It experiences only internal reversible processes, in which its intensive properties (i.e. temperature T_0, pressure P_0) remains constant. In this analysis surrounding temperature and pressure are taken as T_0=30 ^oC (303 K) and P_0=101.325 kPa [13].

2.6.3 Energy and Exergy Analysis

This section presents some of the key aspects of thermodynamics, in terms of energy and exergy, relevant to the current study. Exergy is composed of two important parts. The first one is the physical exergy and the second one is the chemical exergy. The kinetic and potential parts of exergy are negligible. Exergy is defined as the maximum theoretical useful work that can be obtained as a system interacts with an equilibrium state. The chemical exergy is associated with the departure of the chemical composition of a system from its chemical equilibrium. The chemical exergy is an important part of exergy in combustion process [11].

2.6.4 Energy and Exergy Formulations

Mass, energy, and exergy balances for any control volume at steady state with negligible potential and kinetic energy changes can be expressed, respectively, by [5, 12]:

$$\sum \dot{m}_i = \sum \dot{m}_e \qquad \text{.....................} \; (2\text{-}1)$$

$$\dot{Q} - \dot{W} = \sum \dot{m}_e h_e - \sum \dot{m}_i h_i \qquad \text{.....................} \; (2\text{-}2)$$

$$\dot{X}_{heat} - \dot{W} = \sum \dot{m}_e \Psi_e - \sum \dot{m}_i \Psi_i - \dot{I} \qquad \text{.................} \; (2\text{-}3)$$

Where the net exergy transfer by heat ($\dot{X}_{heat}$) at temperature T is given by [22]:

$$\dot{X}_{heat} = \sum (1 - {}^{T_0}/_{T}) \dot{Q} \qquad \text{.........................} \; (2\text{-}4)$$

And the specific exergy is given by

$$\Psi = h - h_0 - T_0 (s - s_0) \qquad \text{........................} \; (2\text{-}5)$$

Then the total exergy rate associated with a fluid stream becomes

$$\dot{X} = \dot{m}\Psi = \dot{m}[\, h - h_0 - T_0 (s - s_0)\,] \; \text{..................} \; (2\text{-}6)$$

If one applies the first and second laws of thermodynamics, one can find the formula for exergy balance as [11, 14]

$$\dot{X} + \sum_i \dot{m}_i \Psi_i = \sum_e \dot{m}_e \Psi_e + \dot{X}_P + \dot{X}_d \qquad \text{.....................} \; (2\text{-}7)$$

For the evaluation of the fuel exergy . Thus, the corresponding ratio of simplified exergy is defined as the following [11]

$$\xi = \Psi / LHV_f \qquad \text{…………………………………..} \quad (2\text{-}8)$$

To find exergy destruction; exergy balance from equation (2-7) can be used.

$$\dot{X}_d = T_0 S_{gen} \qquad \text{…………………….………...…} \quad (2\text{-}9)$$

2.7 Efficiency laws

2.7.1 Energy Conversion Efficiencies

Efficiency is one of the most frequently used terms in thermodynamics, and it indicates how well an energy conversion or transfer process is accomplished. Efficiency is also one of the most frequently misused terms in thermodynamics and a source of misunderstandings.

2.7.2 Exergetic (second law) efficiency

In previous discuss we defined the thermal efficiency and the coefficient of performance for devices as a measure of their performance. They are defined on the basis of the first law only, and they are sometimes referred to as the first-law efficiencies. The first law efficiency, however, makes no reference to the best possible performance, and thus it may be misleading. It is obvious that the first-law efficiency alone is not a realistic measure of performance of engineering devices. To overcome this deficiency, we define second-law efficiency (η_{II}) as the ratio of the actual thermal efficiency to the maximum possible (reversible) thermal efficiency under the same conditions [17]:

$$\eta_{\Pi} = \frac{\eta_{th}}{\eta_{th,rev}} \quad \text{(Heat engines)} \ldots\ldots\ldots\ldots\ldots \text{(2-10)}$$

The second-law efficiency can also be expressed as the ratio of the useful
work output and the maximum possible (reversible) work output:

$$\eta_{\Pi} = \frac{W_u}{W_{rev}} \quad \text{(work-producing devices)} \ldots\ldots\ldots\ldots \text{(2-11)}$$

We can also define second-law efficiency for work-consuming non cyclic (such as compressors) and cyclic (such as refrigerators) devices as the ratio of the minimum (reversible) work input to the useful work input:

$$\eta_{\Pi} = \frac{W_{rev}}{W_u} \quad \text{(Work--consuming devices)} \ldots\ldots\ldots\ldots \text{(2-12)}$$

Also the second-law efficiency is intended to serve as a measure of approximation to reversible operation, and thus its value should range from zero in the worst case (complete destruction of exergy) to one in the best case (no destruction of exergy). With this in mind, we define the second-law efficiency of a system during a process as [17]:

$$\eta_{\Pi} = \frac{\text{exergy recovered}}{\text{exergy supplied}} = 1 - \frac{\text{exergy destryed}}{\text{exergy supplied}} \quad \ldots\ldots \text{(2-13)}$$

2.7.3 Energy and Exergy Analyzed Of Elgunied Sugar Factory

Energy and Exergy analysis are used to analyze the performance of the system. Earlier, most of the power plants are designed by the energetic performance criteria based on first law of thermodynamics but loss of useful energy cannot be justified by first law of thermodynamics, as it does not differentiate between quality and quantity of energy. Energy analysis presents only quantities result while energy analysis presents qualitative result about actual energy consumption. Exergy is maximum theoretical useful work that may be received from energy in a system of ideal machines. It is clear that exergy is not stored in a single process, but may be destroyed due to irreversibility. This study is focused on thermal analysis of energy and Exergy Analyzed of elgunied sugar factory's elements.

There seems to have less number of studies or reports on the energy and Exergy analyses of bagasse based cogeneration systems in the open literatures, because of using bagasse for producing power and process heat is relatively new technology compared to the conventional coal fired power generation [18]. In the recent years, cogeneration systems become the popular technology to implement into many industrial or residential applications as producing power and process heat [18], also in that analysis, the energy efficiency, exergy efficiency, exergy destruction, turbine heat rate are evaluated at 70% and 85% maximum continuous rating (MCR) of back pressure steam turbine in the sugar cogeneration plant. Analysis shows that operating turbine at 85% MCR attract heat rate improvement by 17.01 kJ/kWh as shown in fig.(2-1) and Fig.(2-2). Experimental results show that as power load on steam turbine increases from 70 % to 85 % MCR. Turbine exergy efficiency is lower than its energy efficiency as utilization of heat is at lower temperature than inlet. Turbine exergy loss is 12.32 % and 12.56 % at 70 % and 85 % MCR respectively. There is an improvement observed in turbine heat rate by 17.01 kJ/kWh .

Anjum Munir and others, their proposed study was conducted at Pahrianwali Sugar Mills, Lalian District Jhang. Data was collected for a 60 tons bagasse fired boiler. The boiler was of natural circulation and bi-drum type water tube boiler. The boiler was equipped with super heater, air heater and economizer in order to utilize maximum available heat of flue gases. Boiler efficiency was calculated on the basis of flue-gases temperature leaving the boiler and total heat values of steam. Different instruments and devices were used to record bagasse flow rates and steam flow rates separately [15].

This paper examines the thermodynamics of such a station and then sets out a method to optimise it. Nature is, of course, never that simple [19].

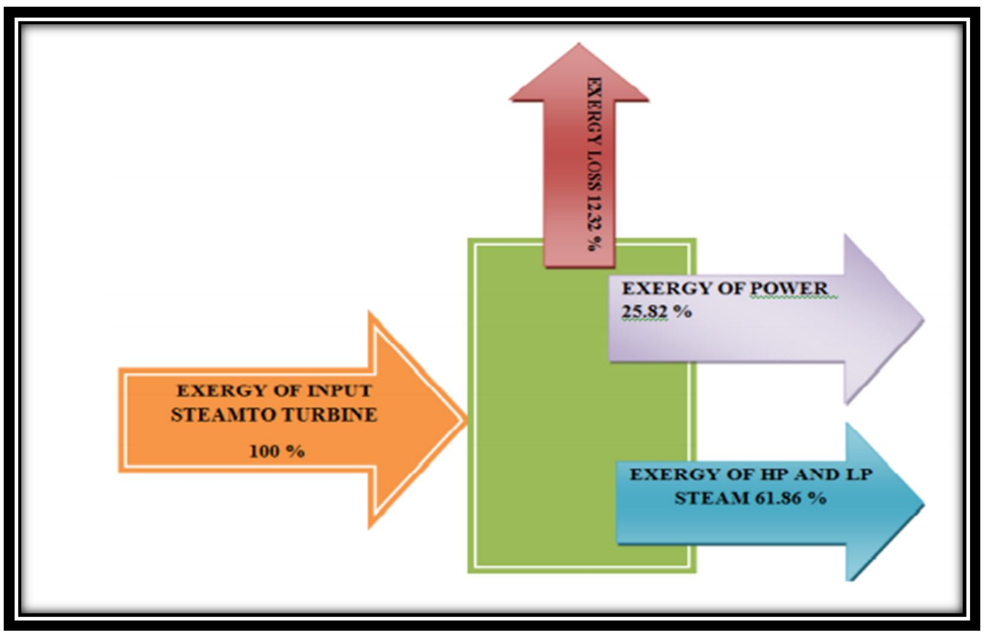

Figure 2.1 Diagram For Exergy Flow Through Steam Turbine At 70 %MCR [19]

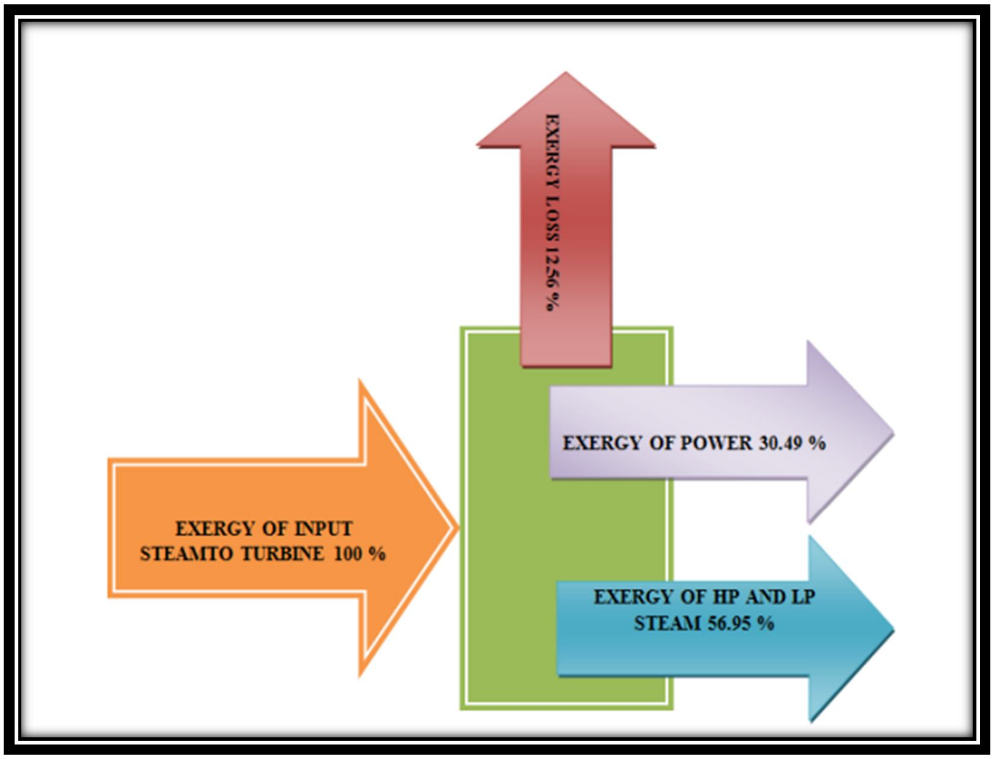

Figure 2-2 Diagram for Exergy Flow Through Steam Turbine At 85 %MCR [19]

Fig. (2-3) shows the distribution of the exergy destruction among the processes, considering data from a typical Brazilian mill. The cogeneration system is responsible for almost 65% of the exergy destruction inside the mill. The ethanol production comes in second place, followed by the sugar production. Hence, modifications in the cogeneration system would have a higher impact in the overall efficiency than modifications on other sub-systems alone [20].

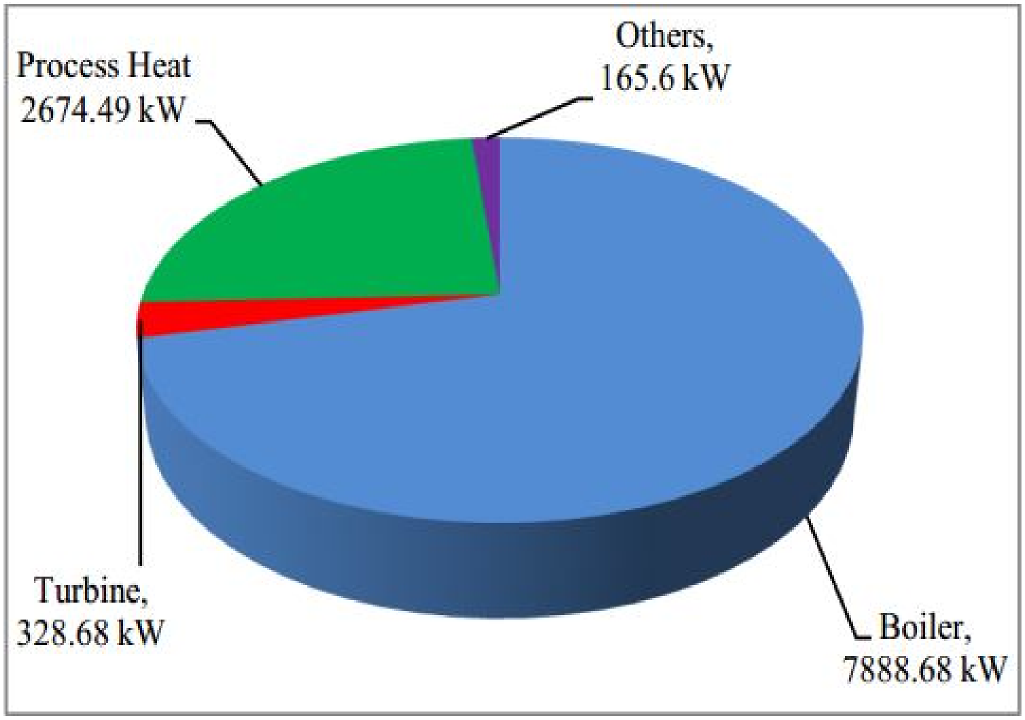

Figure 2-3 Exergy destruction in simple back pressure cogeneration plant [2].

CHAPTER THREE

ENERGY AND EXERGY ANALYSIS OF ELGUNIED SUGAR FACTORY

3.1 Energy and Exergy Analysis of Elgunied Sugar Factory

This section describes the method used to estimate the energy and exergy use, energy and exergy analysis, energy and exergy efficiencies for a boiler, turbine mills, DSHS and to calculate exergy destruction on of processes and this can be achieved by exergy balance.

3.1.1 Gross Calorific Value of Bagasse GCV or HCV

Heat liberated by combustion of 1 kg of bagasse at NTP and all the products of combustion are same conditions at vapors formed by combustion of H2 and moisture in bagasse are considered condensed [15].

GCV = [4600 (1-w) -1200 S] kcal / kg of bagasse

Where w = moisture per unit bagasse

S = Sucrose in bagasse.

If w = 48%   and S = 1.80%

then GCV = [4600(1-0.48) – 1200 * 0.018] = 2370.4 kcal/kg of bagasse [9924.39 kj/kg].

3.1.2 Net Calorific Value of Bagasse NCV or LCV

The amount of heat liberated by 1 kg of bagasse is taken at NTP but water formed by combustion of H_2 and as moisture remains in the vapor form latent heat of evaporation is absorbed from released heat [16].

NCV = [4250 – 1200 S – 4850 w] kg / kg of bagasse

If w = 50% and S = 2%

NCV = 4250 – 1200 * 0.50 – 4850*0.02 = 1801 kcal/kg
{7540.427kJ/kg}

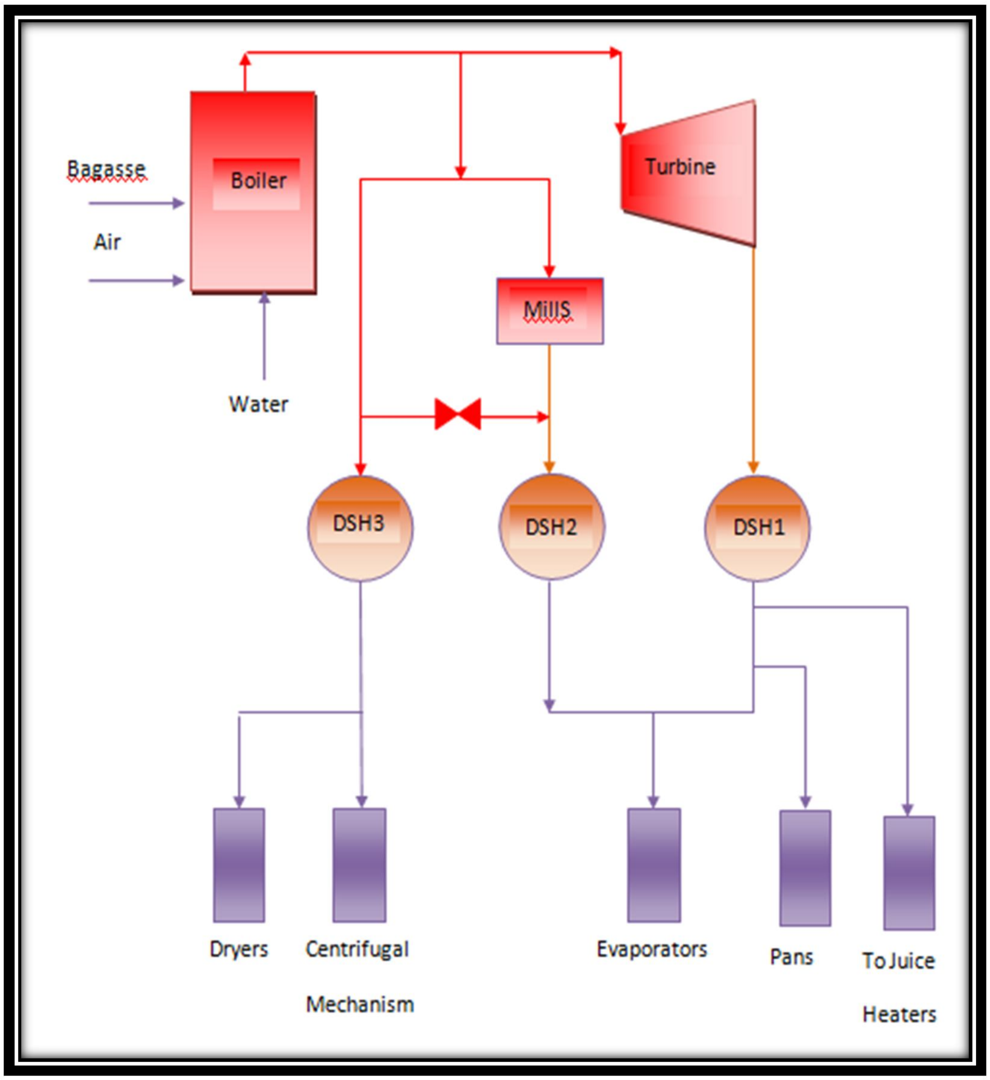

Figure 3.1 Flow diagram of Elgunied Sugar Factory power plant

3.2 Energy and Exergy Analysis of Elgunied Sugar Factory

3.2.1 Energy and Exergy Analysis for a Boiler

A boiler is divided into heat exchanger and combustor as shown in Fig.(3-1). The energy and exergy analysis of these two parts are discussed below.

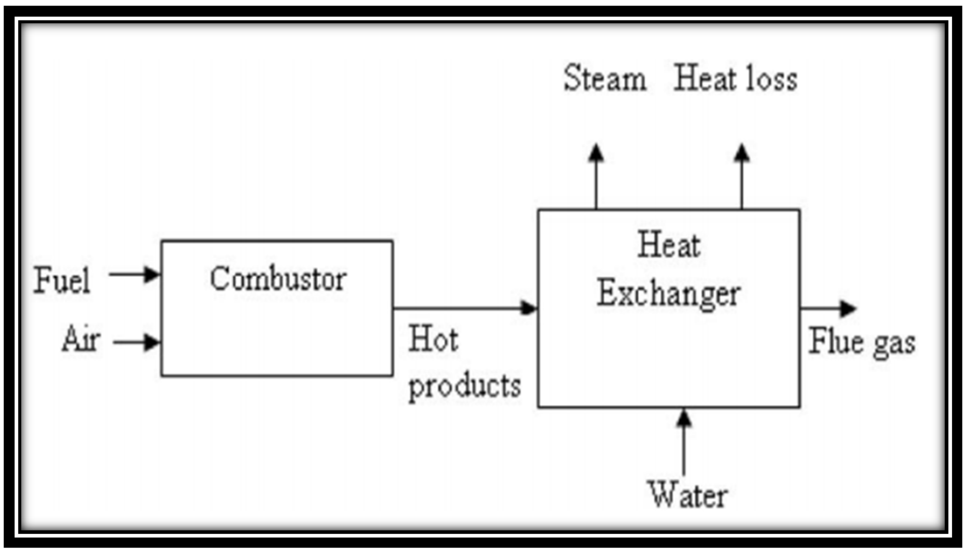

Figure 3.2 Schematic diagrams of combustor and heat exchanger in a boiler

3.2.1.1 First Law Analysis on Combustor

The combustor in a boiler is usually well insulated that causes heat dissipation to the surrounding almost zero. It also as no involvement to do any kind of work (w=0). Also, the kinetic and potential energies of the fluid streams are usually negligible. Then only total energies of the incoming streams and the outgoing mixture remained for analysis. The conservation of energy principle requires that these two equal each others. Besides, the sum of the incoming mass flow rates will be equal to the mass flow rates of the outgoing mixture.

In order to conduct energy and exergy of the boiler, it was necessary to obtain actual samples from the boiler to be studied. The samples were made for the fuel (wet bagasse). Now we can calculate the power output from combustor [13]:

$$\dot{Q}_{in} = \dot{m}_f LHV_f \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(3-1)}$$

3.2.1.2 Second law analysis on combustor

The maximum power output or reversible power is determined from the exergy balance applied to the boiler considering boundary with an environment temperature of T_0 (T_0=30 ^oC) and by assuming the rate of change in exergy in the boiler's system is zero. The exergy balance formulations have been established using methodology developed by:

$$\dot{X}_{in} - \dot{X}_{out} - \dot{X}_{detroyed} = \frac{dX_{system}}{dt} = 0 \quad \ldots\ldots\ldots \text{(3-2)}$$

$$\dot{m}_f\Psi_f + \dot{m}_a\Psi_a - \dot{m}_p\Psi_p - \dot{I}_C = 0 \quad \ldots\ldots\ldots \text{(3-3)}$$

$$\dot{I}_C = \dot{m}_f\Psi_f + \dot{m}_a\Psi_a - \dot{m}_p\Psi_p \quad \ldots\ldots\ldots \text{(3-4)}$$

Where, $\dot{I}_C$ = Exergy destruction, Ψ_a, Ψ_f and Ψ_p are exergy of air, fuel and products respectively.

3.2.1.3 First law analysis on heat exchanger

Heat exchanger is a device where two moving fluid streams exchange heat without mixing. Heat is transferred from the hot fluid to the cold one through the wall separating them. A heat exchanger typically involves no work interactions (w = 0) and negligible kinetic and potential energy changes for each fluid streams. Basically, the outer shell of the heat exchanger is usually well insulated to prevent any heat loss to the surrounding medium. However, there is a little amount of heat that will be dissipated. Taking mass flow rate for heat products as $\dot{m}_p$, mass flow rate for flue gas as $\dot{m}_g$, mass flow rate for water as $\dot{m}_l$ and mass flow rate for steam as $\dot{m}_s$ and since, there is no mixing in heat exchanger, it can be assumed that [1]

$\dot{m}_p = \dot{m}_g = \dot{m}_H$ and $\dot{m}_l = \dot{m}_s = \dot{m}_C$

With these assumptions energy balance can be expressed in eq. (3-5):

$$\dot{m}_H(h_p - h_g) + \dot{m}_C(h_s - h_l) = \dot{Q} \quad \text{.....................} \quad (3\text{-}5)$$

The energy efficiency of the overall boiler can be obtained by using the following formula:

$$\eta_B = \frac{\dot{m}_C\,(h_s - h_l)}{\dot{m}_f\,h_f} \quad \text{..} \quad (3\text{-}6)$$

3.2.1.4 Second law analysis of heat exchanger

By assuming the rate of change in exergy in the boiler's system is zero and the environment temperature at T_0= 30 ^{0}C, the exergy balance can be expressed as [13]:

$$\dot{X}_{in} - \dot{X}_{out} - \dot{X}_{detroyed} = \frac{dX_{system}}{dt} = 0 \quad \text{..................} \quad (3\text{-}7)$$

$$\dot{I}_H = \dot{m}_H(\Psi_p - \Psi_g) + \dot{m}_C(\Psi_l - \Psi_s) \quad \text{................} \quad (3\text{-}8)$$

Hence, the overall exergy balance for the boiler is obtained by adding the exergy balance of the combustor and heat exchanger:

$$\dot{X}_B = \dot{X}_C + \dot{X}_H \quad \text{.......} (3\text{-}9)$$

The exergy efficiency of the overall boiler can be obtained by using the following formula [13]:

$$\eta_B = \frac{\dot{m}_C(\psi_s - \psi_l)}{\dot{m}_f} \quad \text{.......} (3\text{-}10)$$

3.2.2 Energy and Exergy Analysis for a Turbine

The captive power for the sugar plant is generated from steam turbines from the sugar factory process steam. This is cogeneration of power. There is capacity of the sugar plant to generate surplus power to be used as captive power for by products or to be sold to the electricity grid.

The motive energy output depends upon difference heat inlet to the steam turbine and heat outlet from exhaust of the turbine.

Steam turbine system is usually analyzed by energy analysis which uses first law analysis but better understanding is attained when a more complete thermodynamic view is taken, which utilizes the second law of thermodynamics in conjunction with energy analysis, via exergy methods. Pressure drops, kinetic energy, and the change in elevation (potential energy) of different components are negligible; in addition all the presented evaluations are found under steady flow conditions [18].

3.2.2.1 First Law Analysis of Turbine

i. Energy input is equal to product of mass of steam into turbine and its enthalpy at entry [18]:

$$\dot{Q}_{in} = \dot{m}_{s,in} h_{s,in} \quad \text{.......} (3\text{-}11)$$

ii. Energy output is sum of heat extracted and heat exhausted [18]:

$$\dot{Q}_{out} = \dot{m}_{ext}h_{ext} + \dot{m}_{exh}h_{exh} + \dot{m}_{mill}h_{mill} \ldots (3\text{-}11)$$

iii. Work done is equal to the energy in steam at entry to turbine minus that at exit [18]:

$$\dot{W} = \dot{Q}_{in} - \dot{Q}_{out} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3\text{-}12)$$

iv. Actual Power Develop by Turbine Shaft:

P = Generator Power * $\eta^{-1}_{gearbox}$ * $\eta^{-1}_{generator}$

Where:

$\eta_{gearbox}$ Gear box efficiency as per the manufacturer is 98.40 %

$\eta_{generator}$ Generator efficiency as per the manufacturer is 98.03 %

v. Energy Efficiency (1st Law efficiency) of Turbine [18]:

$$\eta_t = (\text{actual power develop by turbine shaft}) \,/\, (\dot{Q}_{in} - \dot{Q}_{out}) \ldots. (3\text{-}13)$$

3.2.2.2 Second law analysis of Turbine

i. Exergy Input :

$$\Psi_{in} = \dot{m}_s(h_s - T_0 S_s) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3\text{-}14)$$

ii. Exergy Out:

$$\Psi_{out} = \dot{m}_{ext}(h_{ext} - T_0 S_{ext}) + \dot{m}_{exh}(h_{exh} - T_0 S_{exh}) \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots\ldots\ldots\ldots\ldots (3\text{-}15)$$

iii. Exergy Destruction in Turbine [18]:

$$\dot{I}_{turbine} = \Psi_{in} - \Psi_{out} - \Psi_{power} \ldots\ldots\ldots\ldots\ldots\ldots (3\text{-}15)$$

Where: $\Psi_{power} = P$

iv. Exergy Efficiency (2nd Law efficiency) of Cogeneration Turbine

$$\eta_T = \frac{\Psi_{power}}{(\Psi_{in} - \Psi_{out})} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3-16)}$$

3.2.2.3 Exergy Destruction

The exergy destruction is always increased when flow exergy is transferring between the components with boundary temperature is higher than ambient. As stating in ―Thermodynamic an engineering approach‖, irreversibility such as friction, mixing, chemical reactions, and heat transfer through a finite temperature difference, unrestrained expansion, nonquasi-equilibrium compression, or expansion always generate entropy [2]. In the most analytical case, the exergy destruction is also referring to lost work or irreversibility, which can be found via the entropy generation and written in Equ (2-9).

Table 3.1: Expressions for Exergy Destruction Rate and Exergy Efficiency for Elgunied Sugar Factory's Components

Component	Exergy destruction rate(MW)	Exergy efficiency
Boiler	$\dot{X}_d = \dot{X}_{fuel} + \dot{X}_{in} - \dot{X}_{out}$	$\frac{\dot{X}_{out}}{\dot{X}_{fuel} + \dot{X}_{in}}$
Turbine	$\dot{X}_d = \dot{X}_{in} - (\dot{X}_{out} + Pow)$	$\frac{\dot{X}_{out} + Pow}{\dot{X}_{in}}$
Mill	$\dot{X}_d = \dot{X}_{in} - (\dot{X}_{out} + Pow)$	$\frac{\dot{X}_{out} + Pow}{\dot{X}_{in}}$
DSH1	$\dot{X}_d = \dot{X}_{in} - \dot{X}_{out}$	$\frac{\dot{X}_{in} - \dot{X}_{out}}{\dot{X}_{in}}$
DSH2	$\dot{X}_d = \dot{X}_{in} - \dot{X}_{out}$	$\frac{\dot{X}_{in} - \dot{X}_{out}}{\dot{X}_{in}}$
DSH3	$\dot{X}_d = \dot{X}_{in} - \dot{X}_{out}$	$\frac{\dot{X}_{in} - \dot{X}_{out}}{\dot{X}_{in}}$

Table 3.2: Main Data for Elgunied Sugar Factory

Parameter	Quantity
Boiler capacity: T/hr of steam (bagasse)	25
Atmospheric pressure in (kPa)	101.325
Atmospheric temperature in (C^0)	30
Lower heating value of fuel (LHV_f) in kJ/kg	7540.427
bagasse consumption in Boiler (kg/s)	13.472

Table 3.3 Chemical Composition of Bagasse

Component	% age	Average %age
Carbon C	**45-46**	**47**
Hydrogen H_2	**5-6**	**6.5**
Oxygen O_2	**43-45**	**44**
Ash	**2-3**	**2.5**

Table 3.4: Properties of the Reference Environment

Composition	T (K)	P (kPa)	h (kJ/kg)	s_0 (kJ/kg.k)
Air	303	101.325	303.208	1.712002
Water	303	101.325	125.79	0.4369

Table 3.5: Operation Data of Plant

Equipment	Position	T (k)	P (bar)
Boiler	in	378	1.2235
	out	643	22.5553
Turbine	in	643	22.5553
	out	433	0.980665
Mill	in	643	22.5553
	out	553	0.8826
DSH1	in	433	0.980665
	out	393	0.980665
DSH2	in	586	0.882599
	out	393	0.980665
DSH3	in	643	22.5553
	Out	453	2.941995

Table3.6: Enthalpy and Entropy Values of Steam Flow

Equipment	Position	h (kJ/kg)	S (kJ/kgK)
Boiler	in	440.17	1.3627
	out	3181.375	7.02555
Turbine	in	3181.375	7.02555
	out	2796.2	7.6597
Mill	in	3181.375	7.02555
	out	3034.64	8.21318
DSH1	in	2796.2	7.6597
	out	2716.794	7.477816
DSH2	in	3114.874	8.349666
	out	2716.794	7.47781
DSH3	in	3181.375	7.02555
	out	2832.85	7.5549

CHAPTER FOUR

RESULTS AND DISCUSSIONS

CHAPTER FOUR

4.1 Introduction

At the end of the energy and exergy analyses, the first law efficiencies were determined by depending on the energy inflow and energy outflow to and from elgunied sugar factory's components. However, the second law efficiencies were calculated based on the exergy inflow and exergy outflow, and the magnitudes and places of the irreversibility during the process of the components.

4.2 Results and Discussions

As can be seen in Table 4.1, the boiler efficiency was found 68.12%.

This chapter essentially describes the results in energy and exergy efficiencies. Besides the efficiency investigations. Table 4-2 provides the details of steam condition at each state, and the operating conditions are taken from Exergy analysis of cogeneration power plants in elgunied sugar industry as a reference temperature and pressure. The exergy destruction is another matter to be emphasized because the study of irreversibility could help to identify where the work or energy lost during the operation and they found that the maximum exergy destruction is estimated in the boiler which is 34.393 MW, also table 4.3 numerically describe the destruction rate for each individual components boiler, turbine, mill and DSHS.

Table 4.1 Boiler Heat Balance

$w = 50\%$ $S = 2\%$ $CO_2 = 14.5\%$, $T_g = 170\ °C$, $T_a = 30\ °C$, $L_u = 2.5\%$, $L_r = 0.5\%$, $L_i = 0.5\%$,			
Heat input GCV	9529.1568		100%
Heat output		(7540.4268-815.2537)×0.975 ×0.995×0.995 = 6491.6373	68.11%
Condensation heat loss		(9529.1568 – 7540.4268)×0.975 ×0.995×0.995 = 1919.6687	20.14%
Sensible heat loss		{(1- 0.5)(1.4×19.8/14.5 – 0.13) + 0.5 } × {711.756 – 125.604} ×0.975×0.995×0.995 = 786.9467	8.25%
Un burnt bagasse loss		9529.1568×0.025 = 238.2289	2.5%
Radiation loss		9529.1568×0.005 = 47.6458	0.5%
Incomplete combustion loss		9529.1568×0.005 = 47.6458	0.5%
Total	9529.1568		100 %

Table4-2 Energy and Exergy Analysis of Elgunied Sugar Factory

Equipment	Position	Flow Rate (kg/s)	Energy (kW)	Exergy (kW)
Boiler	in	25.1996	101584.633	61184.9836
	out	25.1996	69077.215	26692.0236
Turbine	in	9.4498	30063.357	10009.4559
	out	9.4498	26424.09	4553.97
Mill	in	7.9379	25253.3339	8408.015
	out	7.9379	24088.5708	4386.7788
DSH1	in	9.4498	26424.09	4553.97
	out	9.5	25809.5	4347.25
DSH2	in	12.5997	39246.7894	7452.9229
	out	13.15	35725.8	6017.51
DSH3	in	3.15	10021.1722	3336.5559
	out	3.17	8979.99	1744.47

Table 4.3 Expressions of Exergy Destruction Rate and Exergy Efficiency for Elgunied Sugar Factory's Components

component	Exergy destruction rate(MW)	Exergy destruction %	Exergy efficiency %
Boiler	34.393	81.39	43.63
Turbine	1.855	4.39	81.46
Mill	2.857	6.67	66.03
DSH1	0.207	0.49	72.07
DSH2	1.435	3.4	74.18
DSH3	1.592	3.66	80.08
Total	42.202	100	47.09

Due to above analysis and figures we are knew efficient of each part and exergy destruction compared with others component. This text will present significance of equipment due to contribute each part on total exergy destruction for whole factory. Figure (4.1 a) and figure (4.1 b) illustrate exergy destruction for component, no matter about represent specified part on total exergy destruction.

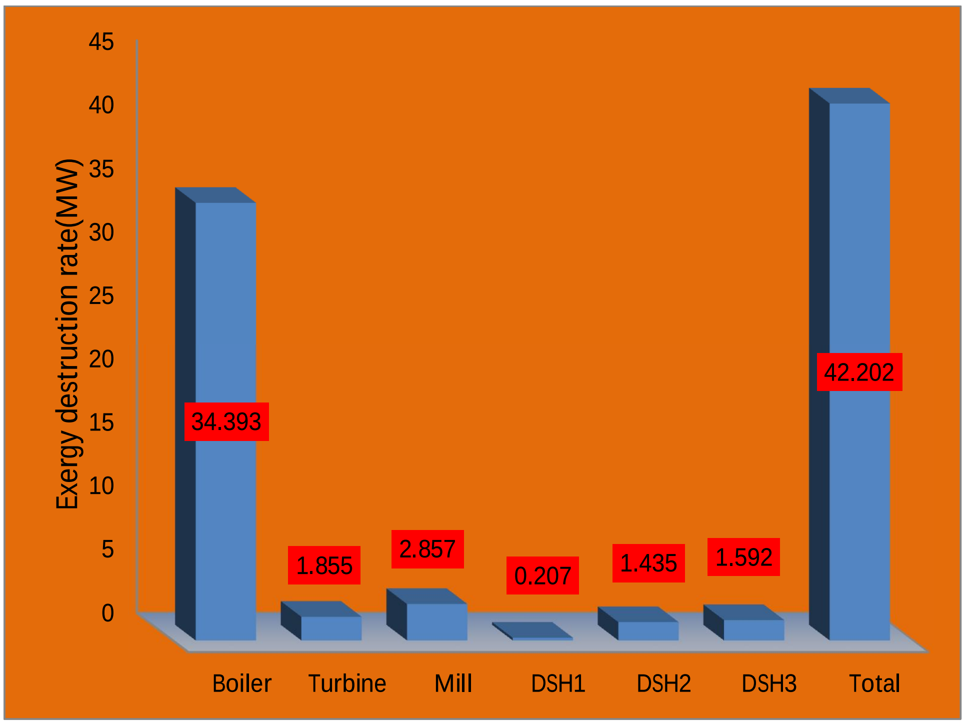

Figure 4.1.a Exergy Destruction Rate (MW) of Components

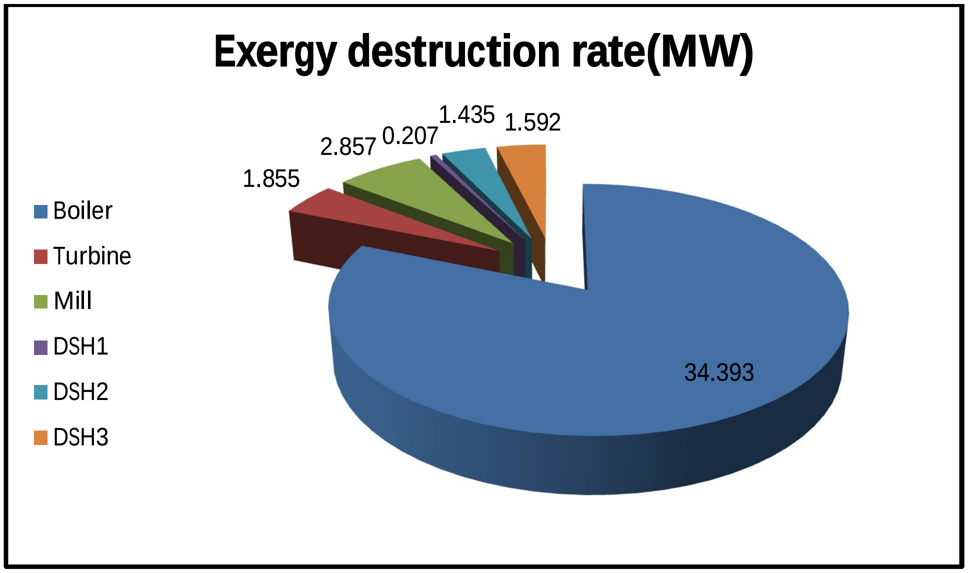

Figure 4.1.b Exergy Destruction Rate (MW) of Components

Exergy Destruction % of Components were shows in Figure (4.2). Figure (4.3) illustrates the compare between exergy destruction % of elgunied sugar factory and Yung C. Lien sugar industry.

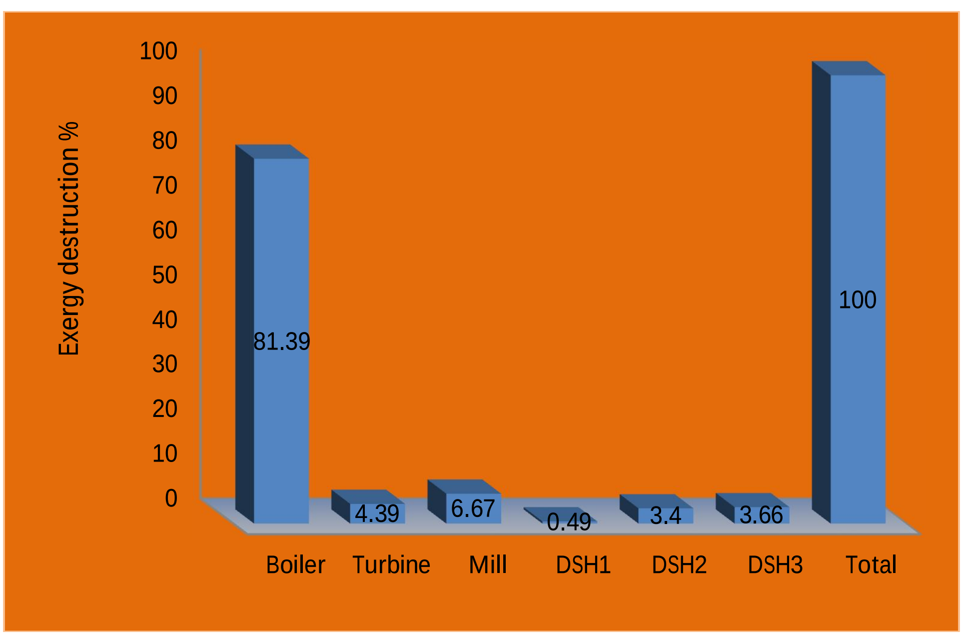

Figure 4.2 Exergy Destruction % of Components

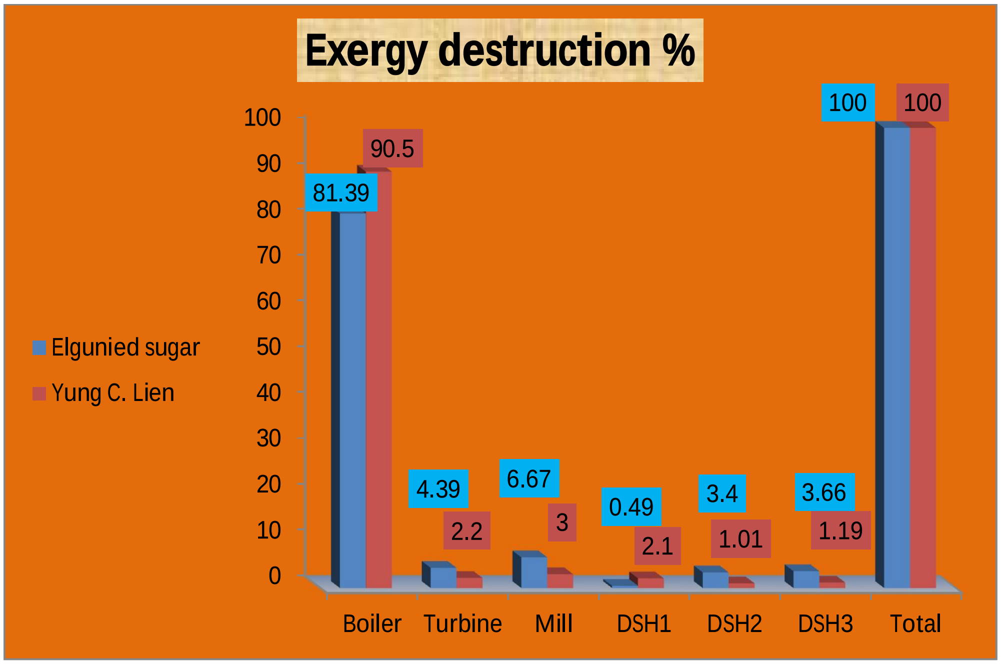

Figure 4.3 Exergy Destruction % of Elgunied Sugar Factory and Yung C. Lien sugar industry

Note that from figure (4.4) exergy efficiency for turbine, DSH3, DSH2, DSH1 and mill (81.46%, 80.08%, 74.18, 72.07 and 66.03) respectively this not consider huge different and may be by misleading; while the exergy efficiency for boiler (43.63%) which considered the lowest one.

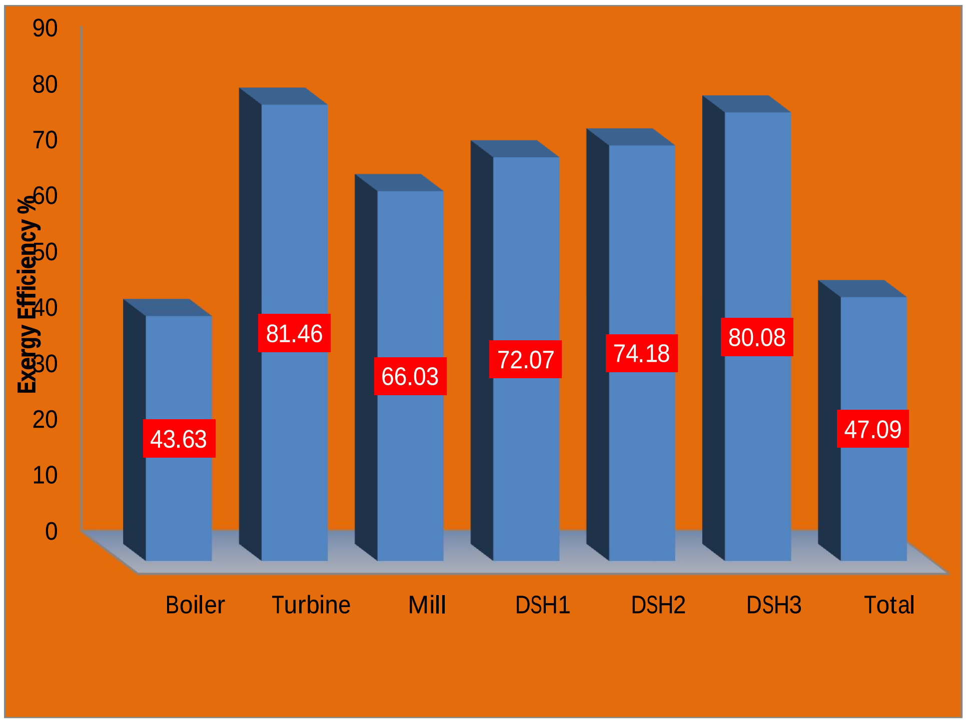

Figure 4.4 Exergy efficiency %

CHAPTER FIVE

CONCLUSION

AND

RECOMMENDATIONS

5.1 Conclusion

In this study, energy and exergy analyses of Elgunied Sugar Factory are presented;

- ❖ The first goal was verification and then finding the energy of each component separately.
- ❖ Exergy analysis shows that the exergy destruction in boiler is accounted for 81.39 % of total system exergy destruction, it can be concluded that the boiler is the major source of irreversibility.
- ❖ The plant exergy efficiency is (47.09 %) which is acceptable but relatively low because elgunied sugar factory plant does not only generate electricity but also requires so much energy in its thermal processes. The calculation of output exergy efficiency is based on both electricity and processed heat output, and the exergy destruction in the boiler and it gives the guideline for engineers on improvement of the process. Therefore, the boiler is a device that also has the lowest exergetic efficiency (43.63 %)
- ❖ For traditional steam cycles with back-pressure turbines (configuration I), a significant amount of surplus bagasse can be obtained with process steam demand reduction, allowing its use as raw material for other by-products of the sugarcane plants.

5.2 Recommendations

The present results and major findings in this thesis demonstrate the recommendations are made when needs of utilizing the results for future work and developments.

- ❖ The boiler efficiency improves with higher NCV which depends on lower bagasse moisture. About 65-75% of heat loss in condensation is due to bagasse moisture. Lower bagasse moisture by slow speed milling with higher quantity and temperature of imbibition water helps to increase bagasse temperature or bagasse sensible heat to improve energy.
- ❖ Must cover the tubes that carry steam with good insulation to reduce the heat losses.
- ❖ Not to increase or reduce the amount of bagasse required for complete combustion limit because it would lead to increase efficiency.
- ❖ It must be stored bagasse well after Derflth dry it and save it in the form of cubes.

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