Sudan University of Science and Technology

College of Graduate Studies & Scientific Research

ENERGY, EXERGY ANALYSIS & IMPROVEMENT FOR BAGASSE -FIRED THERMAL POWER PLANT (ASSALAYA SUGAR FACTORY)

تحليل الطاقة و الاكسرجي وتحسين الآداء لمحطة توليد الطاقة بالبقاس
(مصنع سكر عسلاية)

A thesis submitted to the College of Graduate Studies & Scientific Research, in partial fulfillment of the requirement of the degree of Doctor of Philosophy (PhD) in Mechanical Engineering - Power

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SUDAN UNIVETSITY OF SCIENCE AND TECHNOLOGY
COLLEGE OF GRADUATE STUDIES
SCHOOL OF MECHANICAL ENGINEERING

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This thesis has been approved and accepted in partial fulfillment of the requirements for the degree of doctor of philosophy (Ph. D) in mechanical engineering

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الآية

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

اقْرَأْ بِاسْمِ رَبِّكَ الَّذِي خَلَقَ (1) خَلَقَ الْإِنْسَانَ مِنْ عَلَقٍ (2) اقْرَأْ وَرَبُّكَ الْأَكْرَمُ (3) الَّذِي عَلَّمَ بِالْقَلَمِ (4) عَلَّمَ الْإِنْسَانَ مَا لَمْ يَعْلَمْ (5) كَلَّا إِنَّ الْإِنْسَانَ لَيَطْغَى (6) أَنْ رَآهُ اسْتَغْنَى (7) إِنَّ إِلَى رَبِّكَ الرُّجْعَى (8) أَرَأَيْتَ الَّذِي يَنْهَى (9) عَبْدًا إِذَا صَلَّى (10) أَرَأَيْتَ إِنْ كَانَ عَلَى الْهُدَى (11) أَوْ أَمَرَ بِالتَّقْوَى (12) أَرَأَيْتَ إِنْ كَذَّبَ وَتَوَلَّى (13) أَلَمْ يَعْلَمْ بِأَنَّ اللَّهَ يَرَى (14) كَلَّا لَئِنْ لَمْ يَنْتَهِ لَنَسْفَعًا بِالنَّاصِيَةِ (15) نَاصِيَةٍ كَاذِبَةٍ خَاطِئَةٍ (16) فَلْيَدْعُ نَادِيَهُ (17) سَنَدْعُ الزَّبَانِيَةَ (18) كَلَّا لَا تُطِعْهُ وَاسْجُدْ وَاقْتَرِبْ (19)

صدق الله العظيم

سورة العلق

DEDICATION

To

My parents

A strong and gentle soul whom taught me to trust in Allah, believe in hard could be done work and that so much could be done with little

My beloved family

For earning and honest living for us and for supporting, encouraging me to believe in myself.

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ABSTRACT

Population increment, urbanization, industrializing, and technologic development globally resulted directly in increasing energy consumption. The sugar cane industries represent one of the most important economic sectors globally, and essential source for renewable energy, otherwise, using of bagasse as energy source does not increase the quantity of carbon dioxide in the atmosphere. The most significant pollutant emitted by bagasse-fired boilers, emissions of sulfur dioxide ($SO2$) and nitrogen oxides (NO_x) are very lower than conventional fossil fuels emissions. Through this research, energy, exergy analysis and optimization methods are followed to identified the quality , quantity and location of heat and energy lost through the thermal power plant components, for sugar factories in Sudan (Assalaya Sugar Factory is the case study). For energy, exergy analysis validation Cycle-Tempo software program which designed specifically for thermodynamics plant simulation was used. Constituents and performance of wet and dry bagasse combustion discussed broadly. In Assalaya Sugar Factory thermal power plant, the evaporation coefficient for dry and wet bagasse combustion is 5.05 and 1.84 respectively. The evaporation coefficient for wet bagasse is inversely proportional to bagasse moisture contains. The major of exergy lost due to irreversibility significantly occur in dry bagasse boilers, where it forms 97% of the total exergy lost in power plant system and turbines have highest energy efficiency while condenser has lowest energy efficiency.50% of energy absorbed in boiler disposal in sugar production processes which lead to weak efficiencies of the thermal power plant system. Limited changes on pressure and temperature of steam exhausted from crushing mills and turbine4, the gross efficiency jumped from 14.8% for energy and 37.5% for exergy to 17.2% for energy and 43.6% for exergy.Similar , the net efficiency changed from 13.47% for energy and 34.13% for exergy to 15.9% and 40.3% for energy and exergy respectively.

مستخلص البحث

أدت الزيادة السكانية ،التحضر ،التطورالصناعي، والتنمية التكنولوجية على الصعيد العالمي إلى زيادة استهلاك الطاقة. من ناحية أخري فإن استخدام بقاس القصب كمصدر للطاقة لا يزيد من كمية ثاني أكسيد الكربون في الغلاف الجوي بشكل كبير. حيث أن التلوث البيئي الناتج عن حرق البقاس هو ثاني اكسيد الكبريت و اكاسيد النتروجين ولكن بنسب قليلة جدا بالمقارنة مع امبعاثات الوقود الأحفوري التقليدي. من خلال هذا البحث ، يتم تتبع الطاقة و الاكسرجي بالتحليل لتحديد نوعية ، كمية الحرارة و مكان الطاقة المفقودة وطرق التحسين من خلال مكونات محطات الطاقة الحرارية ، لمصانع السكر في السودان (مصنع سكر عسلاية هو دراسة الحالة). للتأكد من صحة التحليل و الحسابات استخدم برنامج الحاسوب سايكل تنمبو (Cycle – Tempo) الذي صمم خصيصا لمحاكاة الدورات الثرموديناميكية . نواتج و اداء احتراق البقاس الرطب والجاف نوقش على نطاق واسع، وجد ان معامل التبخر في محطة مصنع سكر عسلاية الحارية هو 5.05 و 1.84 عن حرق البقاس الجاف و الرطب علي التوالي ، كما أن معامل التبخر للبقاس الرطب يتناسب عكسيا مع كمية الرطوبة في البقاس. جل الاكسرجي يفقد نتجة لخاصية عدم الرجوعية (irreversibility) تحدث بشكل كبير في الغلاية عند حرق البقاس الجاف، وهي تشكل 97 % من جملة الاكسرجي المفقود خلال المنظومة. وتتمتع التوربينات بأعلى كفاءة في استخدام الطاقة ، في حين أن المكثف لديه أدنى كفاءة في استخدام الطاقة بنسبة 50.٪ من الطاقة التي يتم امتصاصها في الغلاية يتم التخلص منها في عمليات تصنيع السكر ، وهذا بدورة ادي الي ضعف كفاءات المنظومة الحرارية. . تغيرات محدودة على ضغط ودرجة حرارة البخارالخارج من المطاحن التوربينية والتوربينة 4 ، قفزت الكفاءة الإجمالية (Gross Efficiency) من 14.8 ٪ للطاقة و 37.5% للاكسرجي إلى 17.2% للطاقة و 43.6% للاكسرجي. في نفس الوقت تغيرت الكفاءة الصافية (Net Efficiency) من 13.47 ٪ للطاقة و 34.13٪ للاكسرجي ، إلى 15.9٪ و 40.3٪ للطاقة و الاكسرجي علي التوالي.

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LIST OF SYMBOLS

Symbol	Definition	Unit
$E_{x,k}$	Kinetic exergy	MW
$E_{x,p}$	Potential exergy	MW
$E_{x,ph}$	Physical exergy	MW
$E_{x,Q}$	Exergy by heat transfer	MW
$E_{x,w}$	Exergy Transfer by Work	MW
$E_{x,elec}$	Exergy of Electricity	MW
$E_{x,d}$	Exergy destruction	MW
$\widetilde{E_{x,CH\iota}}$	Molar exergy for element	kJ/kmole
$\widetilde{E_{x,CHM}}$	Chemical mixture molar exergy	kJ/kmole
V	Velocity	m/s
$\dot{m}$	Mass flow rate	Kg/s
g	Gravity acceleration	m/s^2
Z	Height	m
T_0	Environment temperature	C^0
P_0	Environment pressure	bar
P	Pressure	bar
h	Specific enthalpy	kJ/kg
h_{da}	Specific enthalpy for dry air	kJ/kg(dry air)
h_g	Specific enthalpy for saturated water vapour	kJ/kg(water)
h_0	Specific enthalpy of environment	kJ/kg
s_0	Specific entropy of environment	kJ/kg.K
s	Specific entropy	kJ/kg.K
s_{da}	Specific entropy for dry air	kJ/kg(dry air).K
s_g	Specific entropy for saturated water vapour	kJ/kg(water).K
S_{gen}	entropy generation	MW/K
C_p	Heat capacity	kJ/kg.K

φ	chemical constituent ratio	Fuel exergy/NCV
ε_f	Specific chemical exergy of fuel	kJ/kg
ε_{phw}	*Specific physical exergy of wet bagasse*	*kJ/kg*
Q	Heat transfer	MW
W	Work	MW
P_{elec}	Electricity generation	MW
η	Energy efficiency	
w	Humidity ratio	kg water/kg dry air)
R	Specific gas constant	kJ/kg.K
$\check{R}$	*Molar gas constant*	kJ/kmole.K
x_i	*Mole fraction* for element	%
σ	Evaporation coefficient	Heat of bagasse / heat of steam
M_v	Heat of bagasse transferred to the steam	kJ/Kg
m	Weight of air used in combustion to theoretical air	kg/kg
γ	Coefficient of incomplete combustion	
β	Coefficient taking into account loses by radiation	
α	Coefficient of loses by unburnt bagasse	
Á	*ash in dry bagasse*	%
A	Ash	kg

LIST OF ABBREVIATIONS

SDGs	Sustainable Development Goals
WEO	Word Energy Outlook
NCV	Net Calorific Value
LPFO	Low Power Fuel Oil2
GCV	Gross Calorific Value
BTU	British Thermal Units
GW	Global Worming
TSP	Suspended Particulates
MW	Mega Watt
EES	Engineering Equation Solver
KATT	Kids Across The Timeline(
T/H	Ton per Hour
Asimptote	Advanced Simulation Programs for Total Energy System
TNO	Netherlands Organization for Applied Scientific Research
TU	University of Technology

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1. Appendix A: Standard Chemical Exergy of Elements
2. Appendix B: Ideal Gas Properties

CHAPTER I
INTRODUCTION

1.1 INTRODOCTION

Population increment, urbanization, industrializing, and technologic development globally resulted directly in increasing energy consumption. This rapid growing trend brings about the crucial environmental problems, contamination , greenhouse effect and acute shortage of electricity[1]. Meanwhile, as the prices of crude oil increase, governments and other institutions are researching the most cost- efficient ways to produce energy from alternative sources. Currently, the major sources for electricity in the Sudan is approximately produced from hydraulic (water), compensated electricity comes from thermal power plant, whereas no sharing in the network from other renewable energy.

Generally, with finite energy sources and huge energy demands, it becomes increasingly important to understand the mechanisms which degrade the quality of energy and energy resources and to develop systematic approaches for improving the systems. Management usage of bagasse as energy source does not increase the quantity of carbon dioxide in the atmosphere. The most significant pollutant emitted by bagasse-fired boilers, emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) are lower than conventional fossil fuels.

Sugar cane is a major commercially grown agricultural crop in the vast majority of states in Sudan, inspite of this; sugar production in Sudan started very late, begging with construction of Elgenead Sugar Factory in 1962 and Halfa Sugar Factory in 1964. Sugar production in Sudan grew steadily to meet rising demands and rapid price increases. Addition factories established in East Sinar 1976, Asalaya 1980, Kinana 1980, and White Nile 2012.The total production of sugar about 800000   tons per year, still 700000 tons per year imported from the neighbor countries.

The sugar production process supplies the fuel (bagasse) for the direct combustion system which provides thermal and electric energy during the production period. Exergy analysis was identified as new technique and methodology for assessments of current power production sites and effective development of innovative future

power generation. Nearly all of the power plants are designed by the energetic performance criteria based not only on the first law of thermodynamics , but the real useful energy loss cannot be justified by the first law of thermodynamics, because it does not distinguish between the quality and quantity of energy. Exergy loosely defined as a universal measure of the work potential or quality of different forms of energy in relation to a given environment. An exergy tells us how much of the usable work potential consumed (irretrievably lost) by the process.

1.2 PROBLEM STATEMENT

Engineers, thermal power experts, and researchers a broadly discussed issues concerning energy, exergy analysis and optimization, specifically for power plant use pulverized coal, natural gases, and heavy or medium oil. But, bagasse thermal power which considered as one of main renewable energy did not given enough attention absolutely.

Addition to that, in previous years bagasse flow rate from crushing mills in Assalaya Sugar Factory exceeds bagasse flow rate to the boiler combustion chamber many times, the surplus bagasse baled and stacked in draught board and sheltered from the weather and climate changes. Availability of bagasse during that period enabled to be used as a dry. But recently, when the engineering administration innovated to extend the power plant to increase electricity generation, hence, rate of bagasse consumption increased dramatically. Shortage of bagasse compulsive to use it directly when it is flow from the crushing mills and contained high water moisture which decrease the calorific value intensively.

1.3 THE OBJECTIVES

The main objectives of this study summarized in the following statements:

1- To follow Energy, exergy methods of thermodynamics analysis to measure quantity and quality of different forms of energy in relation to a given environment and tells us how much of the usable work potential lost through the system components.

2- To study bagasse combustion performance, with or without the moisture content.

To satisfy these objectives the following activities should be implemented:-

➤ Energy, exergy flow rate analysis should be conducted for the overall power plant to determine the efficiencies and heat losses of the major components.

➤ Determination of physical and chemical Constituents for both dry and wet bagasse should be assessed

➤ Identify the gross and net calorific values for wet and dry bagasse

➤ Conduct the air required for wet and dry bagasse combustion

➤ Describe properties of the combustion flue gases

➤ Tempo – simulation software program use to insure the verification and validation of energy, exergy analysis flow rate.

➤ Identify and develop the areas where energy ,exergy losses are being experienced

1.4 SCOPE OF RESEARCH

This study focuses on thermodynamic analysis of direct bagasse combustion power plants in Sudan (Asalaya case study) with respect to the concept of energy, exergy losses, and exergy destruction. Varies options to optimizes and enhance system efficiencies is discuss. Performance of bagasse combustion as dry or wet will discuss in details.

1.5 SIGNIFICANCE OF RESEARCH

Bagasse is the one of main renewable energy source; it does not increase the quantity of carbon dioxide[2] in the atmosphere if burnt directly or gasification-biogas. Today's power management systems need to be agile to accommodate sustainable energy sources, Sudan own six sugar factories and tropical clime, plentiful sunshine, water supplies addition to highly fertile and moisture soil that increasing cane production. Our factories still uses bagasse energy for self production , although can utilized surplus energy on other field. Meanwhile, managing, monitoring, and optimizing energy production, developing the social and economical resources for the country. The energy and exergy methods will identify

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the location and the amount of energy loss through the plant components, therefore significant energy can be saved.

1.6 RESEARCH METHODOLOGY

1.6.1 Overview of approach

The research subject of this work is based on bagasse direct combustion process that used in sugar production (Assalaya case study) and governing equations that describe the thermodynamics properties of steam flow depends mainly on :-

- Continuity equation,
- the energy heat balance equations,
- a general equation of exergy destruction rate
- Energy and Exergy efficiency equations.

These equations applied to defines energy, exergy losses amount and location occurring through the thermal power plant.

1.6.2 Data collection

Thermodynamics properties through power plant components, such as boiler , condenser ,crushing mill, feed water pump, Deaerator, sugar process sector, steam flow rates, turbines, generator characteristics, for Assalaya sugar factory collected from the field and archives master plant. Parameters as temperature, pressure, density, enthalpy, entropy, and specific heat capacity through the thermodynamics cycle of plan will define. Bagasse combustion process carry out in laboratory to identify bagasse chemical, physical contains and the colorific value.

1.6.3 Data analysis

The thermodynamics parameters such as, temperature, pressure, entropy, and enthalpy applied to the governing equations to (energy and exergy equations) obtain the optimum state of plant components. Cycle –temp software program which considering as the thermodynamic modeling and optimization of systems for the production of electricity, heat and refrigeration is use for power plant developing and data analysis verification.

1.7 EXPECTED RESULTS

The main issue expected from this study, that significant amount of bagasse heat and energy lost around the plant system components. If this energy of bagasse exploited effectively, it is sufficient cover the internal use of sugar production process and export the surplus energy as electricity to the national grid network. The evaporation coefficient of wet bagasse is direct inverse proportion to the moisture contains.

CHAPTER II
THEORITICAL BAGGROUND & LITERATURE REVIEW

2.1 INTRODUCTION

Hundreds millions of people facing daily interruptions in electricity supply, compromising their ability to light , cool their homes and interrupting the activity of their firms or farms.

Oil, coal and natural gas still account for more than 80% of primary energy demand - a share that has barely moved over the last 25 years, but now, two consecutive years of declining upstream oil and gas investment in 2015 and 2016 similarly raise concerns about the adequacy of future supply due to political tensions and instability in major resource-rich countries such as Iraq, Libya, Nigeria and Venezuela. Fossil fuels are abundant and relatively cheap. Fossil fuel subject to criticism, but they are not alone in facing an uncertain and difficult future. Decarbonisation of the energy system is one of a number of energy-related policy priorities being pursued by governments around the world. The Paris Agreement on climate change, which entered into force in November 2016, brings together countries representing almost all of the world's greenhouse-gas emissions and energy use[3]: it represents a strong signal of the determination of governments around the world to reduce emissions by accelerating the transition to a cleaner and more efficient energy system. In September 2015, countries marked the 70th anniversary of the creation of the United Nations with agreement on new Sustainable Development Goals (SDGs), including the commitment in SDG 7 to "ensure access to affordable, reliable, sustainable and modern energy for all" by 2030[3]. As the WEO (Word Energy Outlook)has emphasised over many years, the absence of universal energy access is a lamentable failure of the world's energy system, with around one-in-six people in the world lacking access to electricity and two-in-five risking their health in the smoky environments caused by cooking over open fires using solid biomass as fuel. The increased awareness leads world's energy resources are limited and caused many countries to reexamine their energy policies and take drastic measures in eliminating waste. It has also sparked interest in the scientific community to take a closer look at the energy conversion devices and to develop new techniques to better utilize the existing limited resources.

In recent decades, exergy performance analysis based on Second Law of Thermodynamics has found as useful method in, the design, evaluation, optimization and improvement of thermal power plants and other system. Moreover, the exergy method is a useful tool for furthering the goal of more efficient energy-resource use, for it enables the locations, types and magnitudes of wastes and losses to be identified and meaningful efficiencies to be determined. Therefore, it can be said that performing exergy and energy analyses together can give a complete depiction of system characteristics. Such a comprehensive analysis will be a more convenient approach for performance evaluation and determination of the steps towards to improvement direction[4, 5]. Today there is a much stronger emphasis on exergy aspects of systems and processes. The emphasis is now on system analysis and thermodynamic optimization, not only in the mainstream of engineering but also in physics, biology, economics and management. As a result of these recent changes and advances, exergy has gone beyond thermodynamics and become a new distinct discipline because of its interdisciplinary character as the confluence of energy, environment and sustainable development. Exergy and energy analysis is a method that uses the conservation of mass and conservation of energy principles together with the second law of thermodynamics.

2.2 EXERGY CONCEPTS

Exergy of a steady stream of matter is defined as the maximum amount of work obtainable when the stream is brought from its initial state to the dead state by processes during which the stream may interact only with the environment[6].Isidoro[7],2017 , insured that exergy is a state function of the combination system plus environment .Thus, exergy of a stream of matter is a property of two states, the state of the stream and the state of the environment. Exergy had a major impact on the terminology; some classical thermodynamics authors used difference terms such as, availability, available energy, usable energy, and work capability. Exergy in general divided into distinct categories such as:-

2.2.1 Kinetic exergy

Kinetic energy is a form of mechanical energy and can be converted directly into work. Kinetic energy itself is the work potential or exergy of kinetic energy independent of the temperature and pressure of the environment. It is expressed in a mathematical formula as following:-

$$E_{x,k} = \dot{m}\frac{V^2}{2} \qquad (2.1)$$

2.2.2 Potential exergy

Potential energy is a form of mechanical energy and can be converted directly into work. Potential energy itself is the work potential or exergy of potential energy independent of the temperature and pressure of the environment. Potential energy itself is the work potential or exergy of potential energy independent of the temperature and pressure of the environment and expressed mathematically, such as

$$E_{x,p} = \dot{m}gZ \qquad (2.2)$$

Use of environmental reference states for bulk velocity of the fluid stream relative to the surface of the earth V, and altitude of the stream above the sea level Z, is only important where there is direct interaction of the stream with the environment[6]. Therefore, no direct interaction of the fluid stream with the environment in this study, so, kinetic and potential exergy is ignored. Idehai O. Ohijeagbon et al. insured zero values for the height and velocity of the earth surface are used for most analysis[8].

2.2.3 Physical exergy (thermomechanical exergy)

Physical exergy is equal to the maximum amount of work obtainable when the stream of substance is brought from its initial state(T,P) to the environmental state defined by pressure and temperature(T_0,P_0) through a physical processes involving only thermal interaction with the environment[6, 9].Otherwise, physical exergy applied to a restricted dead state associate with thermomechanical equilibrium with the environment, the mass studied was not allowed to pass into or react chemically

with the environment[10]. The flow exergy of a substance is the theoretically obtainable work when the substance is brought into total equilibrium with the local environment[8]. The physical exergy $E_{x,ph}$ can be determined with the enthalpy and entropy values of the stream (characterized by its composition), both at the generic state (T, P), and the environmental state temperatures and pressures (T_0, P0) as:-

$$E_{x,ph} = \dot{m}[(h - T_0 s) - (h_0 - T_0 s_0)] \tag{2.3}$$

But the physical exergy for perfect gases varies with the pressure and temperature, calculated uses the following expression:

$$E_{x,ph} = \dot{m}[C_p(T - T_0) - T_0 \left(C_p \ln \frac{T}{T_0} - R \ln \frac{P}{P_0}\right)] \tag{2.4}$$

2.2.4 Chemical exergy of substance stream

Chemical exergy is equal to the maximum amount of work obtainable when the substance under consideration is brought from the environmental state to the dead state by processes involving heat transfer and exchange of substances only with the environment. Otherwise , chemical exergy defined as the work which theoretically can be produced as mass is permitted to pass into and mix with the atmosphere at (T_0, P_0)[10] . Comparing this definition with a similar definition given earlier for the exergy of a stream of substance shows that chemical exergy is the exergy of a stream of substance when the state of the substance corresponds to the environmental state. Standard chemical exergies of chemical elements and compounds are available in the form of tables presented in appendix (A)[6].the chemical exergy of water (liquid or vapour) is zero, the only exergy taken in considers during water steam flows is the thermomechanical exergy .

2.2.5 Chemical exergy of industrial fuels

Exergy of fuel is examined as a chemical reaction occurs and the products of the reaction reach equilibrium with the environmental composition. Also, descript as a measure of the maximum obtainable work as the substance proceeds to the dead state while exchanging heat solely with the environment.

Solid and liquid industrial fuels are solutions of numerous chemical compounds of elements, usually, unknown nature[6]. This makes it difficult to determine the entropy of the reaction, Δs, of these fuels with a reasonable degree of accuracy. Szargut and Styrylska[6], assumed that the ratio of chemical exergy ε_f, to the net calorific value (NCV) for solid and liquid industrial fuels is the same as for pure chemical substances having the same ratios of constituent chemicals. This ratio is expressed by

$$\varphi = \frac{\varepsilon_f}{\text{NCV}} \tag{2.5}$$

For dry organic substances contained in solid fossil fuels consisting of C, H, O and N with a mass ratio of oxygen to carbon less than 0.667, the following expression was obtained in terms of mass ratios.

$$\varphi_{dry} = 1.0437 + 0.1882\frac{h}{c} + 0.061\frac{o}{c} + 0.0404\frac{n}{c} \tag{2.6}$$

Where the letters c, h, o and n are the mass fractions of C, H, O and N, respectively.

For fossil fuels with the mass ratio 2.67 > o/c > 0.667, which, in particular, includes wood:

$$\varphi_{dry} = \frac{1.0438 + 0.1882\frac{h}{c} - 0.2509\left(1 + 0.7256\frac{h}{c}\right) + 0.0383\frac{n}{c}}{1 - 0.3035\frac{o}{c}} \tag{2.7}$$

For solid moist fuel, the chemical exergy can be written for convenience in the form:-

$$\varepsilon_f\left(\frac{kJ}{kg}\right) = [\text{NCV} + 2442w]\varphi_{dry} + 9417s \tag{2.8}$$

2.2.6 Exergy by heat transfer

Exergy by heat transfer or thermal exergy' is the minimum work required by the combined system of the control mass and the environment in bringing the control mass to the final state from the dead state. Heat transfer is always accompanied by

exergy transfer. Heat transfer Q at a location at thermodynamic temperature T is always accompanied by exergy transfer presented by the following equation[5, 9] :

$$E_{x,Q} = \left(1 - \frac{T_0}{T}\right) Q \qquad (2.9)$$

Assalaya Sugar Factory thermodynamics cycle completely insulated, effect of exergy transfer is neglected.

2.2.7 Exergy transfer by work

Equivalent of a given form of energy as a measure of its exergy, clearly work is equivalent to exergy in every respect. Thus exergy transfer can be specified both in magnitude and direction by the work transfer to whom it corresponds. Therefore, the exergy content of a work flow is the amount of work of the flow exergy transfer by work can simply be expressed as:

$$E_{x,w} = W \qquad (2.10)$$

2.2.8 Exergy of electricity

As electrical energy (active power) can be fully converted into work, the exergy content of electricity is equivalent to the energy content of work, and therefore the energy content of the electrical flow. It can be therefore considered as a particular case of the exergy of a work stream, and expressed as:

$$E_{x,elec} = P_{elec} \qquad (2.11)$$

2.2.9 Exergy destruction (consumption)

All thermodynamic processes are governed by the laws of conservation of mass and energy. These conservation laws state that mass and energy can neither be created nor destroyed in a process. Exergy, however, is not conserved but is destroyed by irreversible processes within a system[11]. An exergy balance must contain a destruction term, which vanishes only in a reversible process. Furthermore, exergy is lost, in general, when a material or energy stream is rejected to the environment. A part of the exergy supplied to a real thermal system is destroyed due to irreversible processes within the system. The exergy destruction $E_{x,d}$ is equal to

the product of the entropy generation S_{gen} within the system and the temperature of the reference environment T_0.

$$E_{x,d} = T_0 S_{gen} \geq 0 \tag{2.12}$$

2.3 REFERENCE ENVIRONMENT

Since the value of the exergy of a thermal system mainly depends on the state of both the system characteristics and a reference environment, a reference environment must be specified prior to the performance of an exergy analysis. The environment is often modeled as a reference environment similar to the actual environment in which a system or flow exists. This ability to tailor the reference environment to match the actual local environment is often an advantage of exergy analysis[5]or exergy is evaluated with respect to a reference environment, so the intensive properties of the reference environment determine the exergy of a stream or system. Definition of the environment taken as that proposed by Baehr(the standard values) where temperature and pressure of this reference environment are normally taken to be $25°C$ and 1 atm, respectively. The chemical composition of atmosphere under standard values consists of air saturated with water vapor, presented on table (2.1).

Table 2.1: constituents of atmospheric air

Component	Mole %
Ar	0.9
Co_2	0.03
H_2O	3.12
N_2	75.65
O_2	20.3

2.4 DEAD STATE

The system, as they say, is in the dead state, when he is in thermodynamic equilibrium with its environment. The dead condition of the system temperature and pressure of the environment (thermal and mechanical equilibrium); it has no kinetic or potential energy relative to the environment and it does not react with the environment (chemically inert). Thus, in addition to pressures and temperatures, the chemical potentials of the substances of the system and environment must be equal. Under these conditions of full thermodynamic equilibrium between system and environment, the system cannot undergo any changes of state through any form of interaction with the environment.

2.5 EXERGY & ENERGY EFFICIENCIES

Engineers make frequent use of efficiencies to gauge the performance of devices and process, Efficiency has always been an important consideration in decision making regarding resource utilization. Efficiency is defined as 'the ability to produce a desired effect without waste of, or with minimum use of, energy, time, resources, etc[6]. For general engineering systems, non-dimensional ratios of quantities are typically used to determine efficiencies.

Ratios of energy are conventionally used to determine efficiencies of engineering systems whose primary purpose is the transformation of energy. These efficiencies are based on the first law of thermodynamics. A process has maximum efficiency according to the first law if energy input equals recoverable energy output, if no energy losses occur. However, efficiencies determined using energy are misleading because in general they are not measures of an approach to an ideal. To determine more meaningful efficiencies, a quantity is required for which ratios can be established which do provide a measure of an approach to an ideal. Thus, the second law must be involved as this law states that maximum efficiency is attained. the second law must be quantified before efficiencies can be defined[5]. Exergy is a measure of the ability to perform work, and from the viewpoint of exergy, maximum efficiency is attained for a process in which exergy is conserved.

Efficiencies determined using ratios of exergy do provide a measure of an approach to an ideal .Consider a control volume at steady-state for which energy and exergy balances can be written, respectively, as:-

Energy in =Energy output in product +Energy emitted with waste   (2. 13)

Exergy in = Exergy output in product + Exergy emitted with waste + Exergy destruction   (2.14)

$$\eta = \frac{Energy\ output\ in\ product}{Energy\ input} = 1 - \frac{Exergy\ loss}{Exergy\ input}$$ (2.15)

$$\eta_x = \frac{Exergy\ output\ in\ product}{Exergy\ input}$$

$$= 1 - \frac{Exergy\ waste\ emission + Exergy\ destruction}{Exergy\ input}$$ (2.16)

2.6 MASS, ENERGY & EXERGY BALANCES

A general balance for a quantity in a system may be written as

Input + Generation − Output − Consumption = Accumulation   (2.17)

Versions of the general balance equation may be written for mass, energy, entropy and exergy. Mass and energy, being subject to conservation laws (neglecting nuclear reactions), can be neither generated nor consumed. Consequently, the general balance written for each of these quantities becomes as:-

Mass input − Mass outpu t = Mass accumulation   (2.18)

Energy input − Energy output = Energy accumulation   (2.19)

Entropy input + Entropy generation − Entropy output = Entropy accumulation (2.20)

Exergy input − Exergy output − Exergy consumption = Exergy accumulation (2.21)

2.7 FUEL COMBUSTION

Heat for energy input can be had from the heat released by fuel during combustion process. Fuels have been provided by nature and the combustion process provides a fluid medium at elevated temperature .during combustion the energy is released by oxidation of fuel elements such as carbon, hydrogen, and

sulfur, high temperature chemical reaction of these elements with oxygen is release energy to produce high temperature gases .

The source of energy that is utilized in fossil-fueled power systems in general, is the chemical energy that is released when a fuel is oxidized by burning in air. The most common fossil fuels are hydrocarbons that is, mixtures of molecules composed of carbon and hydrogen. Upon their complete combustion, the carbon in the fuel is oxidized to carbon dioxide and the hydrogen to water vapor. The energy made available in this oxidation is the net amount released when the carbon and hydrogen atoms are separated from each other and subsequently combined with oxygen to form carbon dioxide and water. If less air is available than is required for a stoichiometric reaction, then not all of the carbon or hydrogen will be fully oxidized and some amount of CO, solid C, or H_2 may be present in the products of combustion.. On the other hand, if extra or excess air is available, then not all of the oxygen available is needed and some will remain unconsumed in the combustion products, but all of the fuel's chemical energy will have been released in the combustion[12]. Bagasse is a waste product of the sugar cane extraction process and has a heating value of up to 7000 kJ/kg (wet). The bagasse represents about 30% of the weight of the raw sugar cane. Bagasse boilers function to incinerate the bagasse and recover the available heat in the form of steam. The overall thermal efficiency for a typical unit is 55% (ranging from 50-70%). In comparison with large fossil fuel fired steam generators this efficiency range is rather low[13].

2.8 ENVIRONMENT IMPACT OF BAGASSE COMBUSTION

Emissions from bagasse boilers to be particulates, sulfur dioxide,and nitrogen oxides are lower than those emitted from burning fossil fuels, due to bagasse lower content of sulfur and low temperature required during the combustion process[14]. Daranee Janghathaikul and Shabbir H. Gheewala carried out experimental analysis concerning Ratchasima Sugar Factory's power plant – Thailand the results evident that bagasse as energy source is friendly to global environment but affects local environment strongly[15].Daraneer presented comparisons of bagasse impact

potential in the environment and the other fossil fuels on table (2.2). The environmental problem of the bagasse-fired power plant is the emission of substantial amount of CO and total suspended particulates (TSP or dust) which contribute to local impacts.

Table 2.2: Impacts potential of bagasse and conventional power plants

Fuel Category	Bagasse	Coal	Oil	Gas
Global Worming (GW)	89.28	1269.91	813.15	569.2
Acidification (AC)	2.21	6.86	3.28	0.95
Photochemical Ozone Formation	1.79	0.008	0.011	0.008
Nutrient Enrichment (NE)	3.62	7.88	3.86	1.84
Solid Landfilled (SL)	783			nil

2.9 FURNACES OF ASSALAYA POWER PLANT

The furnace of bagasse combustion in Assalaya thermal power plant is Spreader – Stoker Furnace Type, which considered as most recent type of furnace .This furnace consists simply of the space situated between the boiler tubes and special mechanical flat grate with continuous discharge of ashes.

The method of feeding the bagasse which constitutes the most original feature of the Spreader –Stoker Furnace .It is effected by means of a steeply sloping chute ; but at the moment this chute discharges the bagasse into the furnace .air under pressure supplied by a pipe located just behind the chute ,is blown in through a longitudinal slot running the whole length of the bottom end of the chute and throws the bagasse violently into the furnace .the bagasse is thus dried and burnt as it falls into the furnace ,and the largest pieces complete their combustion on the grate .E.Hugot [16] evaluated the proportion of bagasse burnt in suspension ranges from 80-90% according to the size of the particles .the quantity of unburnt solids remaining in the ash pit is thus greater than that evacuated by the chimney .it is estimated that a total unburnt loss of 2.5% ,is normally used the unburnt coefficient ($\alpha = 0.975$) .

2.10 ENERGY, EXERGY ANALYSIS &APPLICATION FOR POWER PLANT SYSTEM

Gholam Reza Ahmadi,and Davood Toghraie ,2016, published a paper addressed Energy and exergy analysis of Montazeri Steam Power Plant in Iran. The main objectives aimed to investigating the location of energy and exergy lost through steam cycle of Shahid Montazeri Power Plant of Isfahan with individual unit capacity of 200 MW. all cycle equipment have been analyzed individually and energy efficiency, exergy efficiency, and irreversibility has been calculated for each of them as required. EES (Engineering Equation Solver) software is used for performing analyses. Values and ratios regarding heat drop and exergy loss have been presented for each equipment in individual tables. The results from the energy analysis show that 69.8% of the total lost energy in the cycle occurs in the condenser as the main equipment wasting energy, while exergy analysis introduces the boiler as the main equipment wasting exergy; where 85.66% of the total exergy entering the cycle is lost.

Although the boiler of the Isfahan power plant can work on three types of fuel as fuel oil, gasoline, and natural gas[17], but authors carried out all the calculations in this paper have been done for natural gas only. Gholam proposed several Suggestions to increase the power cycle efficiency and saving energy consumption. Gholam observed that condenser pressure has a significant impact on the load produced by the turbine, increasing the condenser pressure from 0.09 bar to 0.32 bar the load unit reduced from 200 MW to 183.7 MW. As condenser pressure has a large effect on turbines efficiency and finally on production increase, every step toward reducing the condenser pressure will be effective. Gholam suggested removing unevenness around the cooling towers, cutting trees near the towers which have caused reduction of exhaust air- flow from radiators, installing walls directing the air- flow and using mirrors reflecting sun light for heating upper part of cooling towers of the power plant are among strategies for increasing tower efficiency and in turn increasing condenser vacuum. Gholam suggest and used hydro coupling and drivers to changing

electromotor rotation can decrease the consumed power of these equipments.Gholam determined exergy of fuel according to Rosen methodology, which total fuel exergy can be calculated given the molar ratio and exergy of each component.

B. Yeswanth Kumar Reddy et al.[18], 2015, presented in his paper concerning exergy analysis of thermal power plant ,the study on exergy analysis was undertaken on Rayalaseema Thermal power project located in Kadapa, Andhra Pradesh ,India. The capacity of the plant is 5×210 MW. The author insures that energy analysis presented only quantities results while exergy nalysis presents qualitative results about actual energy consumption. The main objective is to analyze the system components separately and to identify and quantify sites having largest energy and exergy efficiency losses. The power plant used pulverized coal for water steam generation. The analysis was applied on the unit with running load of 210 MW. Exergy destruction on the plant components are also presented and energy losses are discussed. The results of the exergy indicate that boiler produces highest exergy destruction of 72 MW. Boiler exergy calculation depends mainly on steam and water properties (input/output), fuel exergy not taken in account.

Christian O. Osueke et al.[19], 2015, deals with Energy and Exergy analysis of Sapele Steam Power plant in Nigeria. The key point in this paper is to identify areas where energy losses are occurring and develop a model that will ensure efficient and effective improvement in a thermal power station. This was accomplished by conducting energy analysis of the overall plant and determination of the efficiencies and energy losses of all the major parts on the power plant in light of experimental data collected from Sapele power plant in Nigeria. Christian deduced that energy losses occurred fundamentally in the boiler where 105 kW was lost to the surrounding, while just 15.7 kW was lost from the condenser system. The rate proportion of the exergy destruction was discovered to be greatest in the boiler system (105.9%) trailed by the turbine (86.53%), and after that the condenser (62.5%). Moreover, the exergy efficiency of the power plant was 11.003% for boiler, 30.315% for turbine and 59.8% for condenser. But Sapele power plant used

natural gas for steam generation, which strategically established in Niger Delta region close to sources of both natural gas feed stock and a river for cooling its steam turbine generators. The author deduced that the exergy efficiency decreases considerably as the reference temperature increases and also, observed that the exergy destruction is very high and increase considerably as the reference temperature decreases. Christian recommended that, this increase in exergy destruction is due to irreversibility in the component, poor design and maintenance of the components which lead to decrease in power supply in Nigeria. Christian analyzed energy and exergy occur in most components of the power plant(turbine, condenser ,deareator, feed water pump, high and low pressure) but he didn't mentioned directly what happened in boiler ,and how exergy of natural gas calculated when used as a fuel in this power plant.

A.Rashad and A. El Maihy[20],2009,presented study of energy and exergy analysis of Shobra El-Khima steam power plant in Cairo , Egypt. The primary objectives of this paper are to analyze the system components separately and identify and quantify the sites having largest energy and exergy losses at different load. The power plant uses Natural gas and heavy fuel oil. It was found that the exergy destruction rate of the turbine is dominant over all other irreversibilities component in the cycle. The authors adopted KATT software to calculate steam/water thermodynamics properties.

Isam H. Aljund[21],2009, studied Energy and exergy analysis of Al-Hussein steam power plant in Jordan. The primary objectives of this paper are to analyze the system components separately and to identify and quantify the sites having largest energy and exergy losses. Energy losses mainly occurred in the condenser where 134 MW is lost to the environment while only 13 MW was lost from the boiler system.The author insured that the boiler is the major source of irreversibilities in the power plant. Chemical reaction is the most significant source of exergy destruction in a boiler system which can be reduced by preheating the combustion air and reducing the air–fuel ratio. Heavy fuel oil with 42943.81 kJ/kg` gross

calorific value is used for steam generation. Exergy of fuel calculated from Szargut and Styrylska theory, assumed the ratio of chemical exergy to the net calorific value for solid and liquid industrial fuels is the same as for pure chemical substance having the same ratios of constituents chemicals.Isam , take the ratio of chemical exergy for heavy oil as fuel is 1.06 and the chemical exegy of the system not taken in account.

  Krishnakumar Dipak Pilankar,2016[22]conducted out through a paper addressed Energy and Exergy Analysis of Steam and Power Generation Plant in a chemical and fertilizer industry. Conventional energy analysis is based on first law of thermodynamics and exergy analysis is based on second law of thermodynamics. The main aims of this paper performing combine energy and exergy analysis on steam and power generation plant. At time of analysis, plant is operated at total steam load of 500 T/H and power generation of 23.8 MW. Natural gases used as fired fuel for steam generation .The physical exergy only considered for exergy analysis.

2.11 ENERGY, EXERGY OF STEAM BOILER

    J. H. Sosa.Arnao and S. A. Nebra[23] ,2011,studied the performance of sugar cane bagasse boilers analyzed through first and second law of thermodynamics .The author seeking to identified amount of irreversibilities happen during the steam production in bagasse boiler. Bagasse delivered to the boiler without moisture, because the system included dryer. Exergy of bagasse calculation depended on Szargut et al.methodology for dry solid fossil fuels only. The author adopted chemical composition for Van der Poel et al. where: Carbon 47.2% ; Hydrogen 6.3% ; Nitrogen 0.3% ; Oxygen 44.5%; Sulphur 0.1% and ash 2.5%.

Lalatendu Pattanayak [24], published, 2014, paper under 'The Influence of Operational Parameters on Boiler Performance: an Exergy Analysis' in an International Journal of Advances in Engineering & Technology , this paper deals with the application of energy and exergy to evaluate the performance of a 500 MW

pulverized coal fired boiler with varying excess air and unburnt carbon percentage. The total exergy considered is only the physical exergy.

Idehai O. Ohijeagbon et al,2015[25], presented through their paper under title "Methodology for Energy and Energy Analysis of Steam Boilers" comprehensive framework of thermodynamics , energy and exergy analysis for industrial steam boilers carried out. The authors determining vital parameters and equations needed in an energy and exergy analysis of steam boilers. Indeed, instructors, researchers and advanced students of engineering, policy makers, and sciences are expected to find this material as a helpful tool to quickly understand fundamental concepts and approach required in energy and exergy analysis of industrial plants. Every fuel has a unique composition and energy content described by its fuel specifications (elements) which considers as essential for determining combustion parameters such as combustion efficiency, minimum air requirements. Low pour fuel oil (LPFO) and diesel oil used for boiler heat sources.

Vijay.D. Shimpi et al, 2015 [26] ,conceptualized out the Energy and Exergy Analysis of high Pressure steam Boiler .authors amplify in energy, exergy differences and definitions. Finally, energy and exergy utilization is analyzed, and applied to the boiler system of 690 T/H boilers in 210 MW coal based thermal power plant.

2.12 Cycle – Tempo Program

Cycle – Tempo was developed jointly by Delft University of technology and by TNO, the Dutch institute for applied research .Since 2011, it is further developed and supported by Asimptote in close cooperation with the original developers within the propulsion and Power group of the TU Delft, constantly expanding Cycle Tempo's capabilities. Cycle – Tempo is a flow sheeting for the thermodynamic analysis and optimization of energy conversion systems, also, considered as one of the few software packages that allows for exergy analysis. It has been around for more than a decade and has a large user community, including major energy companies' consultancy firms and research and development institutes.

The main feature of Cycle –Tempo is the calculation of all relevant mass and energy flows in the system .It has a particularly robust and efficient computational method, which means that you can depend on it to quickly obtain a reliable solution even in the most demanding situation. Also,can perform exergy analysis which provides insight into the exergy flows and losses within subsystems. Furthermore Cycle- Tempo includes an optimizer that can find the maximum value of a merit parameter (e.g. thermodynamic efficiency).Figure 2.1 shown the general feature of Cycle -Tempo

Figure 2.1: Cycle –Tempo feature

Cycle –Tempo have two main components:-

Input and output data

(1) Data input for the following parts:-

➢ **Apparatuses**: summary of the apparatus types available in Cycle-Tempo, presented in table (2.3)

For almost all apparatus the following thermodynamic data can be specified:

PIN   = inlet pressure   (bar)

POUT = outlet pressure   (bar)

DELP = pressure loss in the apparatus (bar)
TIN = inlet temperature (°C)
TOUT = outlet temperature (°C)
DELT = temperature rise in the apparatus (°C)
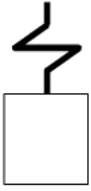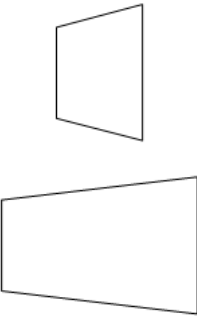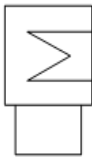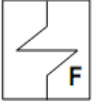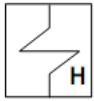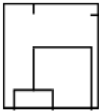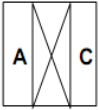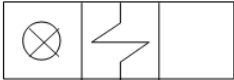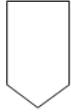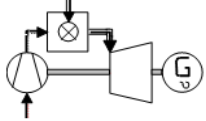
The other data are described and explained for each apparatus type

Table 2.3: apparatus types available in Cycle-Tempo

Type	Default name	System equations		Symbol
1	Boiler	1M		
2	Reheater	1M		
3	Turbine	1M		
4	Condenser	2M /	(EEQCOD = 2; type 6)	
		2M + 1E	(EEQCOD = 1; type 12)	
5	Flash.Heater	2M + 1E		

Type	Default name	System equations	Symbol
6,12	Heat Exchgr.	2M / (EEQCOD = 2; type 6) 2M + 1P (EEQCOD = 1; type 12)	
7	Deaerator	1M + 1E	
8	Pump	1M	
9,11	Node	1M / (EEQCOD = 2; type 9) 1M + 1E (EEQCOD = 1; type 11)	
10	Sink/Source	1M (in case of only 1 pipe connected then 1M only if DELM, DELV or DELVN is specified)	
10	Stack	1M (only if DELM, DELV or DELVN is specified)	
13	Combustor	1M / (EEQCOD = 2) 2M (EEQCOD = 1, or EEQCOD = 2 if LAMBDA specified) (ash pipe connected → +1M)	
14	Valve	2M	
15	Drum	1M + 1E	

Type	Default name	System equations	Symbol
20	Reformer	2M / (EEQCOD = 2) 2M + 1E (EEQCOD = 1) (SFRATI specified → +1M)	
21	Fuel Cell	2M / (EEQCOD = 2) 2M + 1E (EEQCOD = 1) (cooled LTFC → +1M) (UOX specified → +1M) (POWER specified → +1M)	A C
22	Moist. Sepr.	2M / (EEQCOD = 2) 2M + 1E (EEQCOD = 1) (if mass flow of separated moisture is calculated: +1M)	
23	Gasifier	2 M / (EEQCOD = 2) 2 M + 1E (EEQCOD = 1) (ash pipe connected → +1M) (OFRATI or ESTOFR specified → +1M) (SFRATI specified → +1M)	
25	Scrubber	2M	
26	Separator	2M	
27	Reactor	1M	

Type	Default name	System equations	Symbol
28	Saturator	2M	
29	Compressor	1M	
30	Gas turbine	1M if a bottoming cycle is present	
G	Generator	-	
M	Electromotor	-	

➤ **Connections- Pipes**
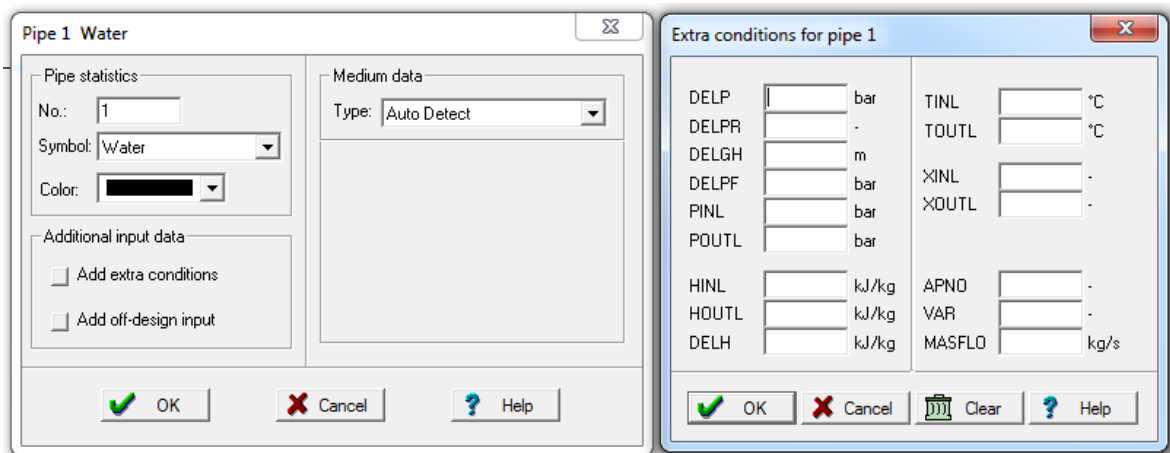
Figure 2.2: Pipe input data window

It is possible to prescribe the pressure, temperature, specific enthalpy or vapor quality in a pipe. In addition a mass flow can be specified. Then an estimate must be specified for a thermodynamic or typical apparatus variable, which is adapted during

the calculation to meet the prescribed mass flow, the windows of pipes input parameters include:

PINL   = pressure at the inlet of the pipe   (bar)
POUTL   = pressure at the outlet of the pipe   (bar)
DELP   = absolute pressure drop in a pipe, pi - po   (bar)
DELPR1)2) = pressure drop in a pipe, (pi - po)/pi   (-)
DELGH2)   = difference in height between inlet and outlet   (m)
 DELPF2) = pressure loss by flow resistance in a pipe   (bar)
HINL   = enthalpy at the inlet of a pipe   (kJ/kg)
HOUTL   = enthalpy at the outlet of a pipe   (kJ/kg)
DELH3)   = enthalpy drop in a pipe, hi - ho   (kJ/kg)
TINL   = temperature at the inlet of a pipe   (C)
TOUTL   = temperature at the outlet of a pipe   (°C)
XINL4)   = vapor fraction at the inlet of a pipe   (-)
XOUTL4) = vapor fraction at the outlet of a pipe   (-)
MASFLO5) = prescribed mass flow   (kg/s)
APNO   = apparatus number for which the estimate of a thermodynamic or an apparatus-typical variable is specified.
DESMAS = mass flow in PIPE at design (kg/s) (default = UNKNOWN)
DESSV   = average specific volume in PIPE at design (m3/kg)
DESDPF = pressure loss by flow resistance in PIPE at design (bar)

➤ Medium Data

The medium data to be specified are:
a. medium type
b. a number of additional data, depending on the medium data.
The medium type indicates the medium library which will be used to calculate the thermodynamic properties. Medium data are specified for pipes. This does not have to be done for each pipe as the program has a procedure which determines the medium type in the other pipes. For each cycle the medium type in at least one pipe should be specified. For closed systems the medium type needs to be specified for just one (arbitrary) pipe. All other pipes automatically will have the same medium type.

o Available medium types

The following medium types are available for Cycle-Tempo
WATERSTM : water/steam
 POTASIUM1 : potassium

GASMIX　　　　: ideal gas mixtures

FUEL　　　　: solid and liquid fuels
NH3-H2O1　: ammonia/water mixtures

Refrigerants　　: Single refrigerants and refrigerant mixtures
Liquids　　　: Liquid secondary refrigerants

➤ **System Data(General Data)**
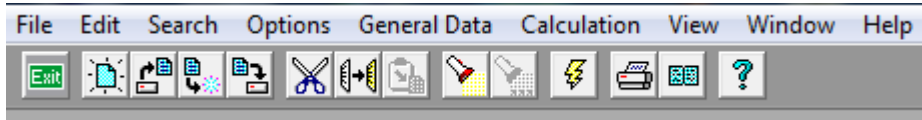
Figure 2.3: General data window

o **Production functions**

A production function is a user defined energy equation, of which the right -hand side represents the amount of energy which is exchanged with the environment.
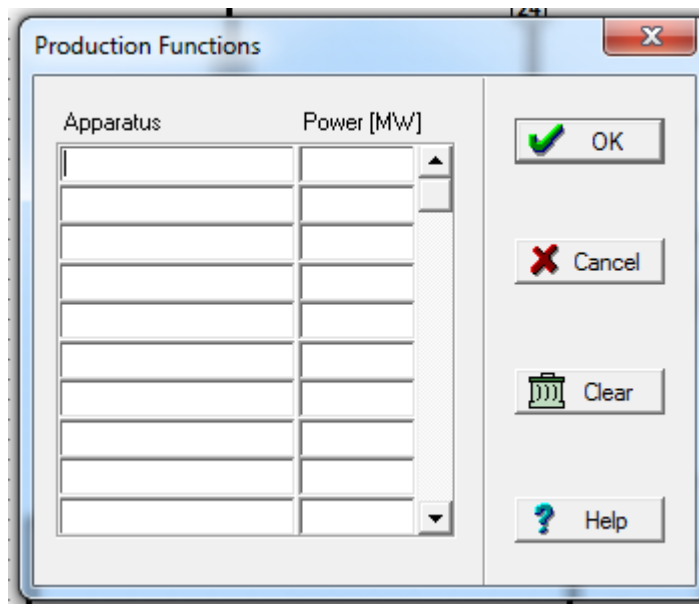
Figure 2.4: Production function window

o **Definition of environment**

The definition of the environment (pressure, temperature and chemical composition) is used to calculate exergy values. The pressure and temperature of the environment are used to calculate heating values.
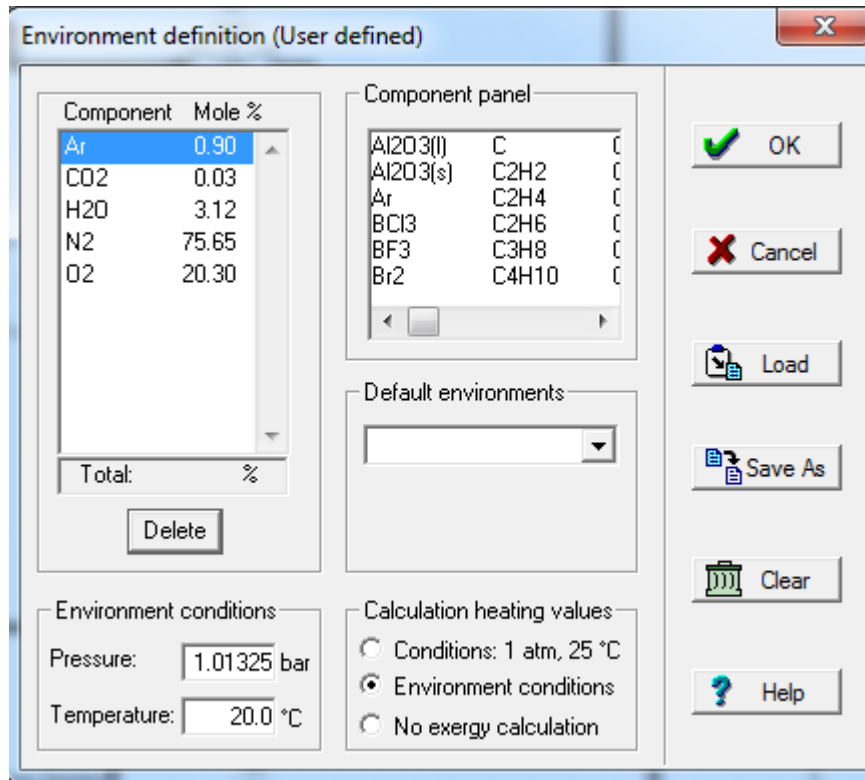
Figure 2.5: Environment definition window

o **Auxiliary power consumption**

Power consumers not modeled can be specified with their electricity consumption, on behalf of the calculation of system efficiencies.

Input parameters

System name = Name of the system or the apparatus which consumes electric power. This name may not be longer than 16 characters.

Power = The electric power which the system or apparatus consumes (kW) (default = 0).
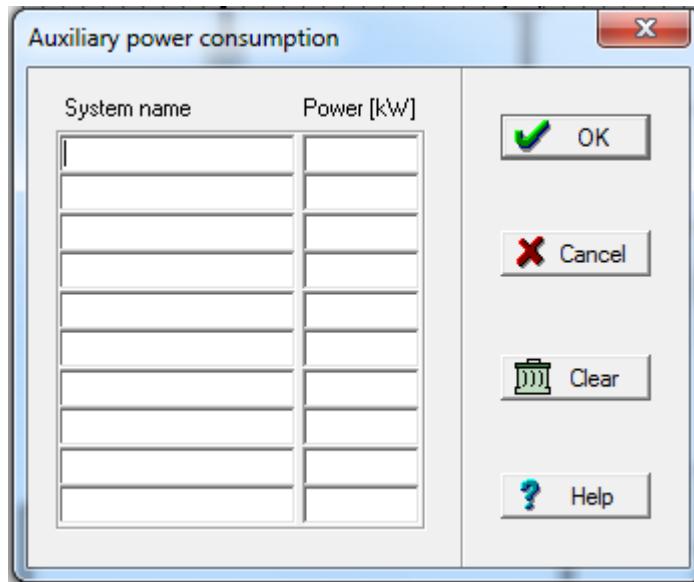
Figure 2.6: Auxiliary power consumption window

> **General calculation settings**

Calculation settings concern the control of the calculation process. The following parameters are available:

Off-design factor = The off-design factor is only used in off-design calculations for initial estimates during the first iteration.

Net frequency = frequency of the electricity grid (Hz) (default = 50 Hz)

Minimum number = minimum number of main iterations of main iterations (default = 0)

Maximum number = maximum number of main iterations of main iterations (default = 25)

Number of extra = number of extra main iterations main iterations (default = 0)

(2) Text output Data

The "Text output" of Cycle-Tempo can be divided into three groups:
1. Output directly related to the input.
2. Output to monitor the iteration process for the compositions and mass flows.
3. Output of the calculated results.

o **Output directly related to the input**

The following components are printed out:

a. A summary relating to the size of the problem, such as number of apparatuses, number of pipes, number of cycles etc.
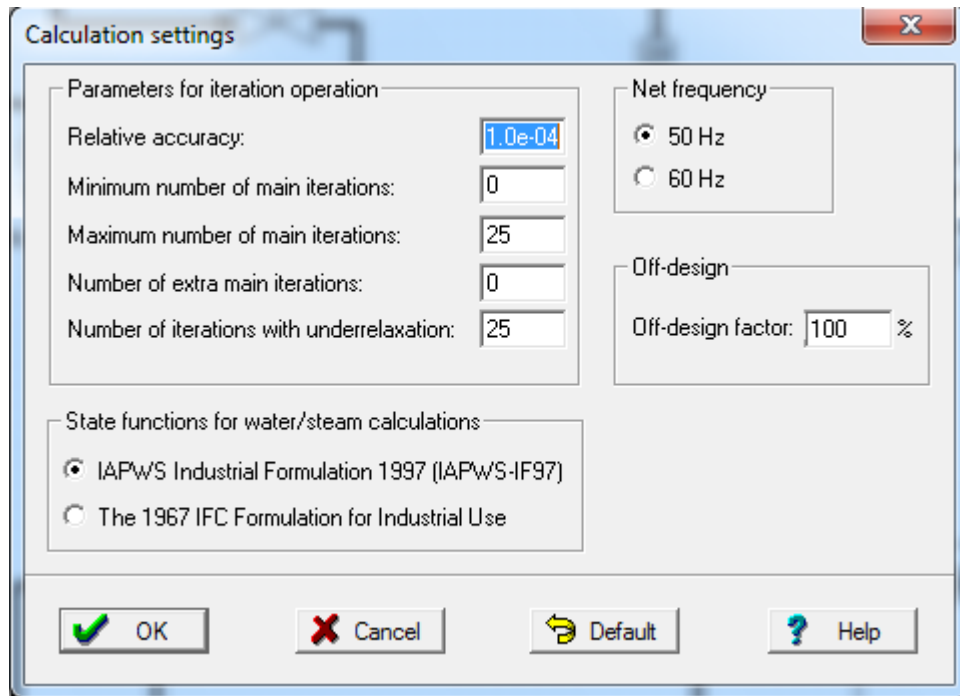
Figure 2.7: Calculation settings window

b. Thermodynamic and typical apparatus data are classified. The pipe input is checked for permitted connections to apparatuses and the prevention of double pipe numbers. In addition a table is printed out with the pipe number specified, the external numbers of the apparatuses at the pipe's inlet and outlet, the pipe code, the number of the cycle of which the pipe is part, and finally the internal pipe number

c. A summary of the medium compositions input, if the medium type is GASMIX or FUEL.

d. A matrix with all the available mass and energy balances.

e. For off-design calculations a summary is given of the design data specified for the surface heat exchangers and turbines.

f. Classified summary of data on generators, turbine drive pumps/compressors and production functions.

g. A summary of how the number of system equations is built up.

```
CONFIGURATION OF THE INSTALLATION
=================================


NUMBER OF APPARATUS              NAPP =  25
NUMBER OF PIPES (LINKS)          NLIN =  31
NUMBER OF THERMAL CYCLES         NCYCLE =  2
TOTAL NUMBER OF TURBINES         NTURB =   3
NUMBER OF TURBINE DRIVEN PUMPS   NTDP =   0
NUMBER OF ABSORTION CYCLES       NABSOR =  0
NUMBER OF PRODUCTION FUNCTIONS   NPRODF =  0
LOAD CONDITION CODE              NDLOAD =  0    =0: DESIGN LOAD RUN
                                          >0: PART LOAD RUN, NDLOAD=NUMBER OF PARTLOAD CONDITIONS (&PARTLD)
DESIGN LOAD FACTOR               DFACTR =1.000000
OUTPUT CONTROL CODE              NPRINT =   4
     0=EXTENSIVE OUTPUT
     1=ALSO PUNCH PARTLOAD DATA
     2=COMPREHENSIVE OUTPUT
     3=MORE COMPREHENSIVE OUTPUT
     4=SHORTENED OUTPUT
ADDITIONAL OUTPUT CONTROL CODE   NXXX =   0
NUMBER OF TRACED APPARATUS        NTRACE =  10

MIN. NUMBER OF MAIN ITERATIONS  MINITM =   0
MAX. NUMBER OF MAIN ITERATIONS  MAXITM =  25
ADD. NUMBER OF MAIN ITERATIONS  MORITM =   0
UNDERRELAXATION INHIBITED AFTER  MAXUR =  25 STEPS
ACCURACY FOR ITERATION            EPS =0.000100
ELECTRICAL FREQUENCY             FREQ = 50.0 HZ

STORAGE USED FOR GENERAL COMMON AREA   =  29574 WORDS OF 4 BYTES


State functions for water/steam calculations:
  IAPWS Industrial Formulation 1997 (IAPWS-IF97)



NUMBER OF EQUATIONS
===================

NUMBER OF PRIMARY MASS EQUATIONS    = 23 NUMBER OF APPARATUS 25 MINUS SINKS WITHOUT MASS EQUATION  2

NUMBER OF SECONDARY MASS EQUATIONS  = 1 NUMBER OF TWO MEDIA APPARATUS TYPES 4,5,6,12,20,21,22,23

NUMBER OF PRESCRIBED MASS EQUATIONS =  6 NUMBER OF TYPES 14,21,25,26,28 AND FOR CERTAIN CONDITIONS: 13,20,22,23

NUMBER OF AUTOMATIC ENERGY EQUATIONS =  2 NUMBER OF TYPES 5,7,11,15 AND IF EEQCOD EQUALS 1: 4,20,21,22,23

NUMBER OF EXPLICIT ENERGY EQUATIONS  =  0 NUMBER OF PRODUCTION FUNCTIONS

MINUS THE NUMBER OF CLOSED CYCLES   = 1 (NUMBER OF OPEN CYCLES = 1)

PLUS THE NUMBER OF ABSORPTION CYCLES =  0

                    MAKES TOGETHER  31 AND NLIN =  31
                    --------------------------------



Cycle-Tempo iteration   0:
--------------------------

Cycle-Tempo iteration   1:
--------------------------

Cycle-Tempo iteration   2:
--------------------------

Main iteration convergence data
===============================
```

2.13 SUMMARY

Exergy analysis is a thermodynamic analysis technique based on the second law of thermodynamics which provides an alternative and illuminating means of assessing and comparing processes and systems rationally and meaningfully. In particular, exergy analysis yields efficiencies which provide a true measure of how nearly actual performance approaches the ideal, and identifies more clearly than energy analysis the causes, degradation, destruction and locations of thermodynamic losses. Consequently, exergy analysis can assist in improving, optimizing designs and should be minimized to obtain sustainable development. Nearly all of the power plants are designed by the energetic performance criteria based not only on the first law of thermodynamics , but the real useful energy loss cannot be justified by the fist law of thermodynamics, because it does not distinguish between the quality and quantity of energy. Ibrahim Dincer et al[5]confirmed that increasing application and recognition of the usefulness of exergy methods by those in industry, government and academia has been observed in recent years. Exergy has also become increasingly used internationally.

Several articles have appeared in the engineering and education literature concerning energy, exergy analysis for thermal power systems.

Gholam Reza et al , 2016,Krishnakumar Dipak Pilanar ,2016, Christain O.Osueke et al ,2015,A.Rashad and A.EL Maiy ,2009,Isam H.Aljund 2009, and B. Yeswanth Kumar Reddy et al,2015 ,introduced appreciative effort concerning energy ,exergy analysis of thermal power plants . Monographs, aimed to identify and quantify the sites through thermal power plant having largest energy and exergy losses and destruction. However; most studies for energy, exergy analysis in the thermal power plants use pulverized coal, natural gas, and heavy oil to generate steam. Studies of bagasse thermal plant, regards energy, exergy analysis mostly very limited, or almost nonexistent. The only issues regards energy ,exergy conception of bagasse carried out by J. H. Sosa .Arnao and S. A. Nebra [23] , 2011 presented the performance of sugar cane bagasse boilers analyzed through first and second law of

thermodynamics .The author seeking to identified amount of irreversibilities happen during the steam production in bagasse boiler. The combustion system includes dryer, therefore, only dry bagasse taken into the analysis consideration. Although ,no dryer system in Assalaya Sugar Factory thermal power plant, and bagasse combustion taken in account as wet and dry. Bagasse chemical composition for Van der Poel et al were adopted by J. H. Sosa.But Elbager[27] approximate and ultimate analysis for bagasse composition were adopted in Assalaya thermal power plant.

CHAPTER III
METHODOLOGY & ENERGY, EXERGY ANALYSIS

3.1 ENTHALPY, ENTROPY OF THE ENVIRONMENT REFERENCE

The ambient environment air contained percentage of water vapour, and treated as a binary mixture of two real gases, dry air and water vapour. enthalpy, entropy of the environment carried out from 2001 ASHRAE Fundamentals Handbook (SI) [28] under Thermodynamic Properties of Moist Air at Standard Atmospheric tables when the pressure is , 101.325 kPa and the temperature is 25 C^0 , usually taken as standard measurement, then, enthalpy and entropy of environment air is determine according to the following equations:

$$h_0 = h_{da} + W h_g \tag{3.1}$$

$$s_0 = s_{da} + W s_g \tag{3.2}$$

From ASHRAE table when temperature is 25 C^0:-
$$h_{da} = 25.153 \, kJ/kg \; ; \; h_g = 2546.47 \, kJ/kg \, , s_{da} = 0.0881 kJ/kgk$$
$$s_g = 8.5565 \, kJ/kgk$$
$$W = fraction \; ratio \left(\frac{x_w}{x_{da}}\right) \times ratio \; of \; molecular \; mass \left(\frac{18.01528}{28.9645}\right)$$

$$W = \left(\frac{x_w}{x_{da}}\right) \times$$
$$\therefore h_0 = 25.15$$
$$\therefore s_0 = 0.088$$

3.2 WATER & STEAM PROPERTIES (WASP) CALCULATOR

Katmar Software, which available on the website (www.katmarsoftware.com) for engineering and risk analysis is a water steam properties calculator which shown in figure 3.1 was used for water and steam properties determination in this research. This program developed to calculates the physical properties of water steam in all popular units; it replaced printed steam tables and eliminates the need to interpolate between data points. The enthalpy and entropy values for each state point in a plant are calculated, and these data are entered in a worksheet (table: 3.2), which can be used to calculate the energy and exergy efficiencies of the cycle.
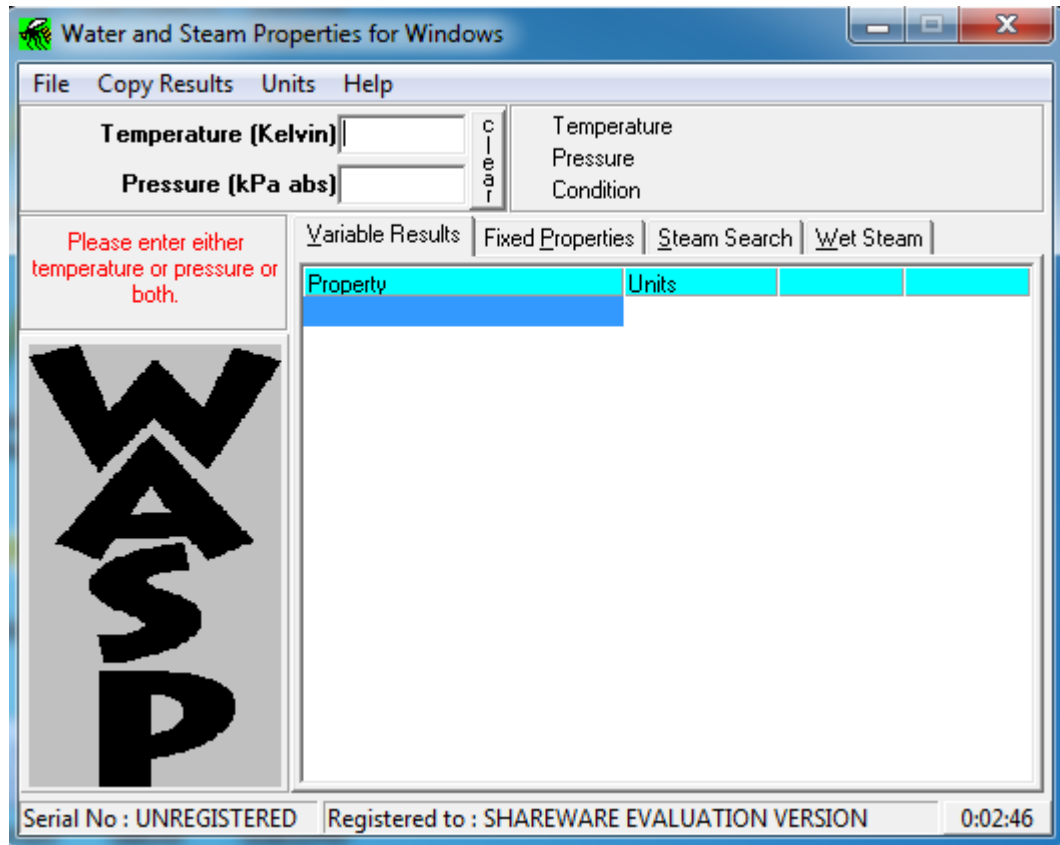
Figure 3.1: Katmar Software –Steam Properties Calculator

3.3 MODELING & DESCRIPTION OF ASSALAYA POWER PLANT

 In order to analyze the energy and exergy performances of this power plant, thermodynamic model and simulation was developed used Cycle – Tempo release 5, Software Packages of Advanced Simulation Programs for Total Energy Systems (Asimptote).

   Schemes of Assalaya sugar factory thermal power plant presented on Figure 2.3.Steam pipelines describing   mass flow diagram for the plant was formed by using the information recorded from both plant archives and onsite data .Assalaya Sugar Factory thermal plant   consist of five boilers(1), usually four in working and one is standby, these boilers generates totally 189.45 tons of superheated steam per hour (T/H); 48.35 T/H of superheated steam transfers to six crushing mill unit(3) that produces 485638 tons of bagasse per year. 65.07 T/H of superheated steam converges to buck pressure power turbine(4) that generates 6.5 MW of electricity.

72.28 T/H of superheated steam delivered to 13 MW turbine(5), which is one of the sugar factory policy to increase the electricity generation and export the surplus to the national net, 3.75 T/H of the steam considered as losses. Specific technical operating condition concerning Assalaya Sugar Factory presented in table 1.3.The thermodynamics parameters, such as, temperature, pressure, enthalpy, mass flow, and power generation were determined for each node and presented in table 3.2.

Table 3.1: Assalaya Thermal Power Plant Operating Conditions

Description	Value	Unit
Bagasse flow rate to boiler	26	kg/s
Bagasse Production	113.36	T/H
Bagasse Production per year	485638	ton
Bagasse to yard	3.88	kg/s
Superheated steam flow rate	51.58	kg/s
Temperature of Superheated Steam	380	^{0}C
Pressure of Superheated Steam	25	bar
Feed water temperature (to boiler)	105	^{0}C
Feed water flow rate	53.67	kg/s
Feed water pressure	40	bar
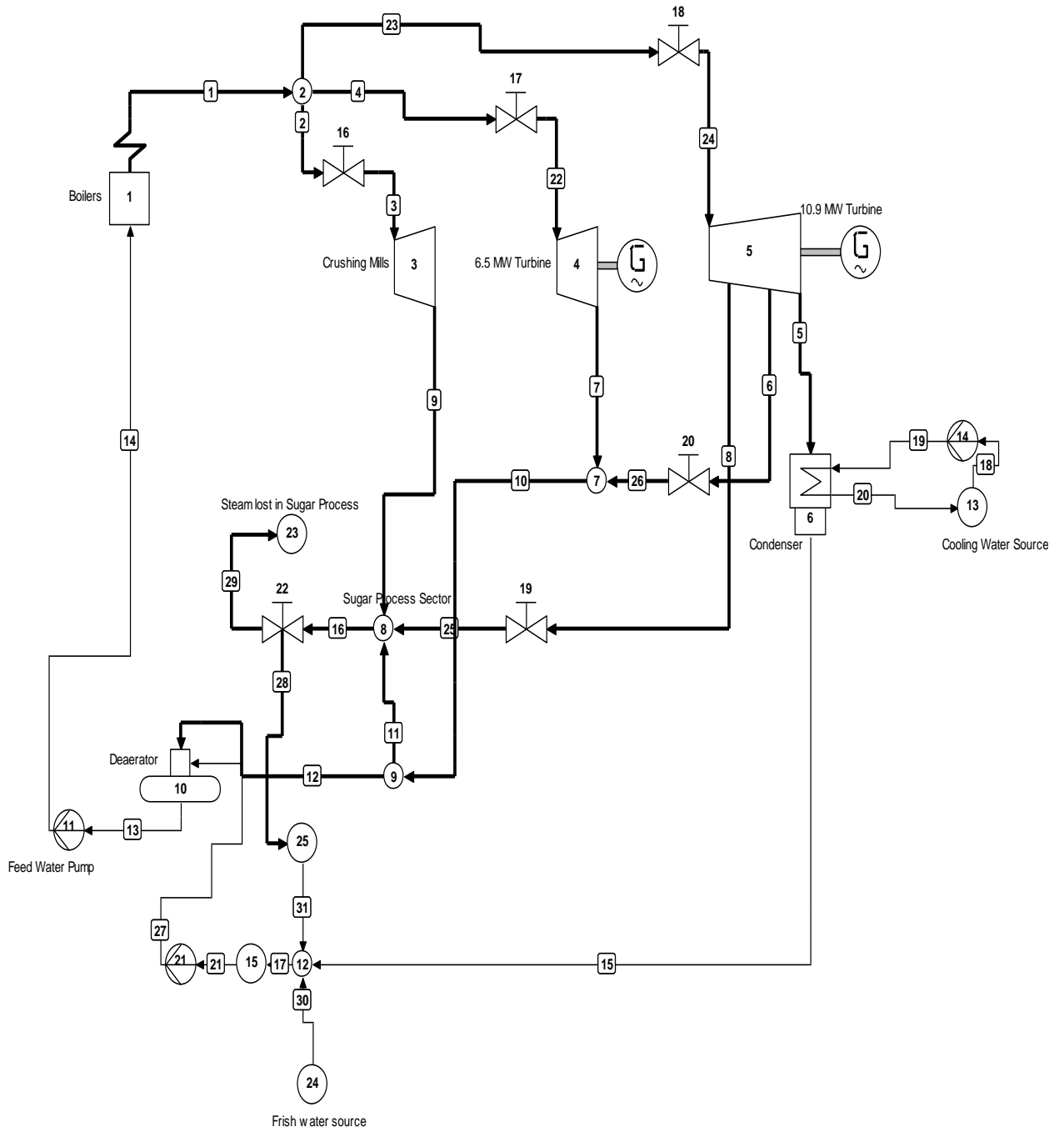
Figure 2-3 :Schematic diagram of Proposaled Assalaya Sugar Factory Thermal Power Plant

Table 3.2: Main Flow Data for Pipes in Assalaya Sugar Factory Thermal Power Plant

point	Mass flow Rate m (kg/s)	Pressure P (bar)	Temperature T (C⁰)	Specific Enthalpy h (KJ/kg)	Specific Entropy S (kJ/kg k)	Specific Exergy ε (kJ/kg)	Total Energy flow E (MW)	Total Exergy flow Eₓ (MW)
1	51.583	25	380	3194.0	6.956	1133.354	164.756	58.46
2	13.430	25	380	3194.0	6.956	1133.354	42.895	15.22
3	13.430	25	380	3194.0	6.956	1133.354	42.895	15.22
4	18.075	25	380	3194.0	6.956	1133.354	57.731	20.48
5	9.858	1.1	105	2685.0	7.3403	509.7746	26.469	5.02
6	8.340	1.1	173	2820.7	7.6581	550.7225	23.525	4.59
7	18.075	2.7	177	2819.2	7.2459	672.1199	50.957	12.15
8	1.880	4	205	2870.6	7.184	742	5.387	1.4
		1.1	200	2874.3	7.7746	569.588	5.4037	1.07
9	13.430	1.9	150	2769.0	7.2921	608.1454	37.187	8.17
		1.1	147	2768.9	7.5355	535.47	37.186	7.19
10	26.415	2.7	175	2815.0	7.2368	670.6331	74.358	17.71
11	22.86	1.1	171	2816.8	7.6494	549.4164	64.392	12.56
12	3.10	1.1	171	2816.8	7.6494	549.4164	8.732	1.70
13	51.583	1.1	102	427.31	1.3291	44.32384	22.042	2.28
14	51.583	40	102	430.17	1.3259	48.13792	22.189	2.48
15	9.858	1.1	47	196.74	0.6645	11.90433	1.939	0.12
16	38.17	1.1	163	2803.	7.6337	540.2973	106.990	20.62
17	48.028	1.1	77	322.23	1.0394	25.62	15.476	1.23
18	833.33	1	28	117.34	0.4086	8.80091	97.783	7.33
19	833.33	10	28	118.18	0.4084	9.70054	98.483	8.08
20	833.33	7	35	147.14	0.5045	10.008	122.62	8.34
		6	35	147.05	0.5046	9.9	122.54	8.25
21	48.028	1.1	60	251.07	0.8310	16.59235	12.058	0.79
22	18.075	25	380	3194.0	6.956	1133.354	57.731	20.48
23	20.078	25	380	3194.0	6.956	1133.354	64.129	22.75
24	20.078	25	380	3194.0	6.956	1133.354	64.129	22.75
25	1.880	1.1	200	2874.3	7.7746	569.588	5.4037	1.07
26	8.340	2.7	173	2810.9	7.2277	669.2462	23.443	5.58
27	48.028	6.1	60	251.21	0.8309	16.76217	12.065	0.805
		1.1	60	251.07	0.831	16.59	12.058	0.796
28	30.00	1.1	163	2803	7.6337	540.2973	84.09	16.21
29	8.168	1.1	163	2803	7.6337	540.2973	22.9	4.4
30	8.17	1.1	28	117.34	1.3291	8.80091	0.958	0.072
31	30	1.1	100	419	1.3066	42.72	12.570	1.28

3.4 BAGASSE SPECIFICATION

Bagasse is the solid fibrous material which leaves the delivery opening of the last mill of the tandem after extraction of the juice. It is the residue from the milling of cane.

A typical chemical analysis of washed and dried bagasse might show:-

- 45%- 55% Cellulose
- 20%- 25% Hemi- cellulose
- 1% - 4% Ash
- > 1% waxes

Also bagasse defined as a heterogeneous material containing around 30% -40% of"pith" or fibre ,which is drived from the core of the plant and is mainly parenchyma material or stem which makes up the balance. These properties make bagasse particularly problematic for paper manufacture and have been the subject of a large body of literature. Bagasse is often used as a primary fuel source for sugar mills. When burned in quantity, it produces sufficient heat energy to supply all the needs of a typical sugar mill, with energy to spare. Generally, Sudan Sugar factories use dry bagasse but sometimes obliged to use wet bagasse according to the technical cultivation causes and the action plan that followed recently to increase electricity generation.

3.4.1 Chemical & physical constituents of dry bagasse

The chemical composition of dry bagasse varies slightly according to different authors, since these variations are not large, mean standard composition properties of the dry bagasse used by E. Huget [16] compared with the proximate and ultimate analysis of Sudan Sugar factories dry bagasse analysize and carried out by Elbager[27]used thermogravimetric analyzer . Also, Gamble, G. E. [29]evaluated the chemical and physical constituents of Australian mill bagasse, the results of the authors presented the table 3.3 below.

Table 3.3: Ultimate Analysis of dry bagasse in % by mass weight

N 0.	Composition	E.Hugot[16]	Elbager[27]	Gamble, G. E.[29]	Australia Manual[30]
1	Carbon C	47%	46.95%	46%	48.43%
2	Hydrogen H	6.5%	6.06%	6.5%	5.83%
3	Oxygen O	44%	42.44%	46 %	45.4%
4	Nitrogen N	-	0.13%	-	0.31%
5	Sulfur S	-	0.08%	-	0.03%
6	Ash *A*	2.5	4%	-	-

3.4.2 Chemical & physical constituents of wet Bagasse

Poor work at the mills will give a bagasse of 50% moisture, while very good work will give a bagasse of 45% moisture. It is still difficult, even in a modern mill, to obtain figures as low as 44%. The most frequent values are: $W = 45 – 50$ % [16] in addition to water, the bagasse contains:

(a) Insoluble material, consisting mainly of cellulose, and comprising the fiber content of the bagasse.

(b) Substances in solution in the water (this water obviously originating in the juice and the imbibition), consisting of sugar and impurities.Chemical and Physical Constituents of Wet Bagasse can be determined from its ultimate and proximate analysis. Data concerning Constituent of wet bagasse combustion is very limited, but N.Magasiner [31] ,Gamble, G. E.[29] and Charles Mbohw[32] summarized valuables data concerning wet bagasse constituent. Percentages of Nitrogen and Sulfur are not appearing in wet bagasse constituent analysis, so the effects of Nitrogen and Sulfur ignored in wet bagasse system process in this research. The proximate and ultimate analysis for wet bagasse constituent presented in table 3.4

Table 3.4: Ultimate and approximate Analysis of Wet Bagasse in % by mass weight

Constituent	N.Magasiner [31]	Gamble,G. E.[29]	Charles Mbohw[32]
Carbon (C)	22.5%	23.25 %	22.5 %
Hydrogen (H)	3%	3.25 %	3 %
Oxygen (O)	23 %	23 %	23.0
Moisture (H_2O)	50 %	50 %	50%
Ash(A)	1.5 %	-	1.5%
Total	100 %	99.5 %	100%

Ash of wet bagasse determined conventionally from dry bagasse percentage, according to the following formula:[30]

$$A = Á(1 - 0.01w) \tag{3.3}$$

The ash of wet bagasse on Asalaya sugar factory can be evaluated according to the above formula as:

$$A = Á(1 - 0.01w) = 4(1 - 0.01 \times 50) = 2\%$$

3.5 DRY BAGASSE CALORIFIC VALUE

The heating value of bagasse depends mainly on percentage of bagasse moisture content and fiber in sugarcane. Experts and researchers indicate that increase in the calorific value of bagasse with the reduction in its moisture content so as to improve its calorific value and this would improve the boiler efficiency[33].

3.5.1 The Gross Calorific Value of dry bagasse

The only methods of dry bagasse assessment calorific value presently available are direct laboratory analysis or the use of calculation formulas derived for specific conditions. In spite of considerable differences in appearance between varieties of cane, the gross calorific value (GCV) of dry bagasse varies only about two percent for bagasse from different countries[34]and a universal value based on values from several difference authors abut (GCV= 19256   kJ kg^{-1}) . But Bureau of Sugar Experiment Stations Brisbane, Australia evaluated the gross calorific value of dry bagasse (GCV= 19 400 kJ kg^{-1}). Experimental test for Asalaya Sugar Factory dry bagasse carried out in Sudan University of Science and Technology laboratories to determine its gross and net calorific values of bagasse by used the bomb calorimeter,

under Khartoum climate conditions, temperature 36 ^{0}C and pressure 1.007 bars. Observation of the temperature raised and become 1.9 ^{0}C ,this amount of heat enables us to determine the capacity heat of combustion (gross of calorific value) and estimated about GCV_{dry}=19 497.61 Kj.Kg^{-1}.

3.5.2 The Net Calorific Value of dry bagasse

The Net (low) Calorific Value (NCV) gives a more accurate indication of heat practically obtainable, but there is no means of determining it directly. It is therefore necessary to calculate this value ,the convention adopted of subtracting from G.C.V the weight of hydrogen per unit mass of bagasse [16].The South African Sugar Technologist's Association[34] developed equation to predict the net calorific value of bagasse given as:

$$NCV_{dry} = GCV_{dry} - 21936\, H(KJ.Kg^{-1}) \tag{3.4}$$

The NCV_{dry} dry bagasse in Assalaya Sugar Factory calculated from equation 3.4 resulted as: $NCV_{dry} = 18\ 071.77\ KJ.Kg^{-1}$

3.6 CALORITIC VALUE OF WET BAGASSE

Sugar mill wet bagasse is used as a fuel in sugar industry worldwide. The gross calorific value of wet bagasse depends mainly on the water content of the bagasse .Decrease of bagasse moisture content enhance boiler efficiency due to the increasing of the calorific value; and also results in higher energy loss because the fuel moisture carries that latent heat of vaporization up the stack [35]. The South African Sugar technologists Association [34],and E .Hugot [16] summarized the main formulas developed by varies authors conventionally used to calculates the gross calorific value of wet bagasse in sugar industries , Von Pritzelwitz formula is considered to be more accurate and used this research ,   because it is values sited in the medially .

(a)Von Pritzelwitz formula:

$$GCV_{wet} = [19632 - (30.98\%\ \text{brix}) - (196.32 \times \%\ \text{moisture}) - (196.$$
$$\times\ \%\ \text{ash})]\ \text{kJ}.\text{kg}^{-1} \tag{3.5}$$

$$NCV_{wet} = [18\,335 - (30.98 \times \%\text{ brix}) - (207.6 \times \%\text{ moisture})$$
$$- (183.35\%\text{ ash})\text{kJ. kg}^{-1} \tag{3.6}$$

(b) Hessey formula:

GCV_{wet}= [19 946 - (34.12 brix % sample) - (199.46 moisture % sample) - (199.46 ash % sample)] kJ.kg^{-1} (3.7)

NCV_{wet}= = [18 603 - (34.12 brix % sample) - (210.3 moisture % sample) - (186.03 ash % sample)] kJ.kg^{-1} (3.8)

(C)The South African Sugar Technologists' Association (S.A.S.T.A)

GCV_{wet} = [19 605 - (196.05 moisture % sample) - (196.05 ash % sample) - (31.14 brix % sample)] kJ.kg^{-1} (3.9)

NCV_{wet} = [18 309 - (3 1.14 brix % sample) - (207.6 moisture % sample) - (196.05 ash % sample)] kJ.kg^{-1} (3.10)

Data collected from the Sudan sugar factories and experimental test indicated that the wet bagasse contented 50% moist, 2% brix , and 2% ash.

Comparisons of GCV$_{wet}$ and NCV$_{wet}$ (kJ.kg^{-1}) for the above author's formulas concerning wet bagasse have produced in table 3.5.below:-

Table 3.5: GCV and NCV for wet bagasse

Description	Hessey [34] (kJ/kg)	Von Pritzelwitz [16, 34](kJ/kg)	S.A.S.T.A[34] (kJ/kg)
GCV$_{wet}$	9505.84	9361.4	9348.12
NCV$_{wet}$	7647.7	7526.34	7474.62

   The Gross and Net Calorific Value of wet bagasse in Assalaya Sugar Factory computed according to Von Pritzelwitz formulas(equation 3.5 & 3.6) and taken as 9361.4 kJ.kg^{-1} and 7526.34 k J.kg^{-1} respectively

3.7 AIR REQUIRED FOR DRY BAGASSE COMBUSTION

The reaction of fossil fuels such as, coal, natural gas and biomass fuel with the oxygen liberate heat. The main combustion products of fuels burning are carbon dioxide and water .The combustion is the reaction of fuel substance with air or pure oxygen to form combustion products.

To ensure complete and efficient combustion in a furnace, an adequate supply of oxygen must be brought into contact with the fuel. The simplest way of measuring combustion efficiency is to determine the percentage of carbon dioxide, oxygen and carbon monoxide in the, flue gases. A trace of carbon monoxide indicates incomplete combustion ,whilst the carbon dioxide indicates of complete combustion[16]. Generally, combustion of bagasse analysis, for both wet and dry base on chemical reactions method (Stoichiometric quantities).Therefore, according to it is constituents and subsequently masses of air required for complete burning is estimated. To perform complete combustion carbon present in bagasse transforms into carbon dioxide, hydrogen into water, and sulphur into sulphur dioxide that presented by equations a,b,c,and d below. Thus it is obvious that the total mass before combustion and after combustion remains constant; although the elements exist in form of different chemical compounds in reactants and products based on mass.

a. $H_2 + O \rightarrow H_2O$
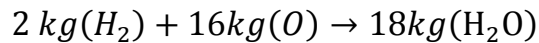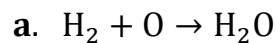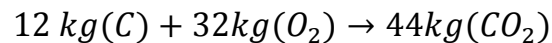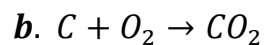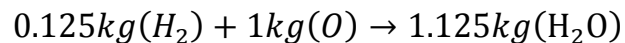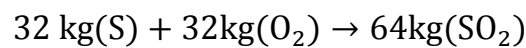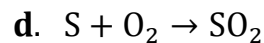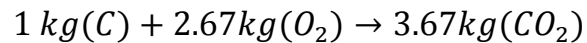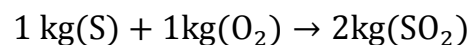
$2\ kg(H_2) + 16kg(O) \rightarrow 18kg(H_2O)$
Or
$0.125kg(H_2) + 1kg(O) \rightarrow 1.125kg(H_2O)$
b. $C + O_2 \rightarrow CO_2$
$12\ kg(C) + 32kg(O_2) \rightarrow 44kg(CO_2)$
Or
$1\ kg(C) + 2.67kg(O_2) \rightarrow 3.67kg(CO_2)$
d. $S + O_2 \rightarrow SO_2$
$32\ kg(S) + 32kg(O_2) \rightarrow 64kg(SO_2)$
Or
$1\ kg(S) + 1kg(O_2) \rightarrow 2kg(SO_2)$
It is noted from the chemical formulas, 1kg of hydrogen shall require 8 kg of oxygen, 1 kg of carbon shall require 2.67 kg of oxygen and 1 kg of sulfur shall require 1 kg of oxygen. So, ash and nitrogen assumed not undergo any chemical reaction.

From table 3.6 the minimum air required theoretically for dry bagasse complete combustion is 5.7 kg/kg of bagasse. Moreover, this air is heated by combustion flue gases in heat-air component, and the temperature is raised from ambient to the under grate air temperature which is 250°C.

Table 3.6: air required for dry bagasse combustion

N0.	Composition	Percentage (kg/kg)	Oxygen required (kg/kg composition)	Oxygen required (kg /kg bagasse)	Mass of air required for combustion(kg/kg bagasse) (air having 23 % oxygen)
1	Carbon C	0.4695	2.67	1.252	$\dfrac{1.3132 \times 100}{23}$
2	Hydrogen H	0.0606	8	0.4848	
3	Oxygen O	0.4244	-	- 0.4244	
4	Nitrogen N	0.0013	-	-	
5	Sulfur S	0.0008	1	0.0008	
6	Ash *A*	0.0476	-	-	-
			Total	1.3132	5.7

3.8 AIR REQUIRED FOR WET BAGASSE COMBUSTION

For conditions by supplying only the quantity of air theoretically necessary for wet bagasse; combustion would be poor and incomplete. In order to obtain complete combustion for wet bagasse, without unburned bagasse and all carbon burns to CO_2, it is necessary to supply a certain excess of air[16]. Charles [36] explained that wet bagasse which content 50% moisture, practically requires excess air for complete combustion not less than 48% of the theoretical air. By Stoichiometric quantities analysis method (table 7. 3), the theoretical air required for 1 kg of wet bagasse combustion is 2.65 kg, and the actual air required (after addition of excess air) for wet bagasse complete combustion is 4 kg/kg of bagasse.

Table 3.7: air required for wet bagasse combustion

N0.	Composition	Percentage (kg/kg)	Oxygen required (kg/kg composition)	Oxygen required (kg /kg bagasse)	Mass of air required for combustion(kg/kg bagasse)(air having 23 % oxygen)
1	Carbon (C)	0.225	2.67	0.6	
2	Hydrogen	0.03	8	0.24	
3	Oxygen (O)	0.23	-	- 0.23	
4	Moisture	0.50	-	-	
5	Ash(A)	0.015	-	-	
			Total	0.61	2.65

3.9 DRY BAGASSE FLUE GASES

Considerable energy, exergy is carried out with the stack gases such as a product of combustion eventually pass through a stack and are released to the environment.

Flue gases that liberated during dry bagasse combustion determined theoretically from composition of combustion products .In this research assumed all gases formed during combustion process exits through the chimney as flue gases. The main elements of gases that formed during bagasse combustion included carbon dioxide, water vapour, nitrogen, and sulfur dioxide see table 3.8.

Table 3.8: Dry bagasse flue gases

N0.	Composition	Percentage (kg/kg)	Products	Mass of flue gases (kg)
1	Carbon C	0.4695		1.72
2	Hydrogen H	0.0606		0.54
3	Oxygen O	0.4244	-	-
4	Nitrogen N	0.0013	N_2	5.15
5	Sulfur S	0.0008	SO_2	0.0016
6	Ash A	0.0476	A	-
	Total			7.41

The Flue gases in Assalya Sugar Factory departure the air –heater with a temperature of 350 C^0. The total amount of flue gases that liberated during dry bagasse combustion is 7.41 kg / kg of bagasse.

3.10 WET BAGASSE FLUE GASES

The flue gases liberate during wet bagasse combustion included all the elements defined in dry bagasse combustion, addition to the oxygen that contained in the excess air, see table 3.9.

Table 3.9: Wet bagasse flue gases

N0.	Composition	Percentage (kg/kg)	Products	Mass of flue gases (kg)
1	Carbon (C)	0.225		0.825
2	Hydrogen (H_2)	0.03		0.27
3	Oxygen (O_2)	0.23		0.23
4	Nitrogen (N_2)	-	N_2	2.4
5	Moisture(H_2O)	0.5		0.5
6	Ash(A)	0.015	A	-
7	Total			4.225

The total amount of flue gases that liberated during wet bagasse combustion is 4.22 kg / kg of bagasse.

3.11 PHYSICAL EXERGY OF DRY BAGASSE FLUE GASES

Bagasse combustion produced gases assumed to be perfects gases ,T.J.Kotas and Kanit Manatura[6, 37] gives an expression for the specific physical exergy determination which is directly propositional to the differences in the temperature and pressure of a system with respect to the reference environment . For a perfect gas as following

$$\varepsilon_{phd} = \left[c_p(T - T_0) - T_0(c_p ln \frac{T}{T_0} - R \, ln \frac{P}{p_0} \right] \tag{3.11}$$

In Asalaya Sugar Factory, bagasse burnt under atmospheric pressure (P=P_0), and a flue gases leave the air –heater with a temperature 350 C^0, equation (11.3) become:

$$\varepsilon_{phd} = c_p(T - T_0) - T_0 \left(c_p ln \frac{T}{T_0} \right) \tag{3.12}$$

Table 3.10: Physical exergy of dry bagasse flue gases

Products	Mass of flue gases (kg)	c_p (kJ/kgk)	ε_{phd} (kJ/kg)	E_{phd} (kJ)
CO_2	1.72	1.014	106.6795	183.4888
H_2O	0.54	1.93	203.0488	109.6464
N_2	5.15	1.071	112.6763	580.283
SO_2	0.0016	0.7	73.64465	0.117831
Total	7.41			873.536

The physical exergy of flue product gases per kg of dry bagasse = 873.5 KJ/kg

The total physical exergy loss when the combustion rate of bagasse equal (26 kg/s)

= 26×873.5= 22.71MW

3.12 CHEMICAL EXERGY OF DRY BAGASSE FLUE GASES

Dry bagasse during it is combustion librated turbulent hot gases respect to the bagasse moisture content. Chemical exergy of bagasse combustion flue gases carried out according to the T.J. Kotas[6] expression for chemical exergy of mixture gases given as following

$$\widetilde{E_{x,CH}} = \sum_i x_i \widetilde{E_{x,CHi}} + \breve{R}T_0 \sum_i x_i ln x_i \left(\frac{KJ}{kmole}\right) \tag{3.13}$$

Chemical product molar exergy $\widetilde{E_{x,CHi}}$,taken from standard enthalpy of devaluation and standard chemical exergy of chemical elements tables. Reproduced from tables T.J.Kotas[6] appendix A. Analysis and value of chemical exergy of dry bagasse flue gases presented in table 3.11

Table 3.11: chemical exergy of dry bagasse flue gases

Products	Mass of flue gases (kg)	Molecular Weight	*Mole Number* (kmole)	Mole fraction (x_i)	(kJ/Mole) ($\widetilde{E_{CHi}}$)	$x_i \times \widetilde{E_{CHi}}$	$x_i \ln x_i$
	1.72	44	0.039	0.154	20140	3101.56	- 0.288
	0.54	18	0.03	0.118	11710	1381.78	- 0.252
N_2	5.15	28	0.184	0.72	690	496.8	- 0.236
SO_2	0.0016	64	0.000025	0.0001	303500	30.35	- 0.0009
Total	7.41		0.253025			5010.49	0.7769

$$\widetilde{E_{x,CHM}} = 5010.49 - 8.1344 \times 298.15 \times 0.7769 = 3126.29 (\frac{kJ}{kmole})$$

The average molar mass for combustion products =

$$\frac{mass\ of\ products}{number\ of\ products\ moles} = \frac{7.41}{0.253025} = 29.28\ kg/kmole$$

The chemical exergy of flue gases for unit dry bagasse = 106.77 $(\frac{KJ}{kg})$

The chemical exergy loss during dry bagasse combustion =106.77×26 =2.77 MW

The total exergy lost with flue gases during dry bagasse combustion =chemical exergy +physical exergy =25.48MW

3.13 PHYSICAL EXERGY OF WET BAGASSE FLUE GASES

Physical exergy of wet bagasse is defined according to the T.J.Kotas theorem for gas specific physical exergy determination presented in equation 3.12. The physical exergy of wet bagasse flue gases mainly depends on bagasse flue gases products which presented in table 12.3

Table 3.12: Physical exergy of wet bagasse flue gases

Products	Mass of flue gases (kg)	c_p (kJ/kgk)	ε_{phw} (kJ/kg)	E_{phw} (kJ)
CO_2	0.825	1.014	106.6829	88.01343
H_2O	0.77	1.93	203.0553	156.3526
O_2	0.23	0.966	101.6329	23.37556
N_2	2.4	1.071	112.6799	270.4318
Total	4.225			538.1733

The total physical exergy lost during combustion of wet bagasse =
538.1733 kJ/kg ×26 kg/s = 14 MW.

3.14 CHEMICAL EXERGY OF WET BAGASSE FLUE GASES

From equation 13.3 and appendix A; the chemical exergy of wet bagasse flue gases
was calculated and presented in table 3.13

Table 3.13: Chemical exergy of wet bagasse flue gases

Product	Mass of flue gases (kg)	Molecular Weight	*Mole Number* (kmole)	Mole fraction (x_i)	*molar exergy* (kJ/Kmole) ($\widetilde{E_{CHi}}$)	$x_i \times \widetilde{E_{CHi}}$	$x_i lnx_i$
CO_2	0.825	44	0.0187	0.122	20140	2457.08	-0.25
H_2O	0.77	18	0.042	0.273	11710	3196.83	-0.35
O_2	0.23	32	0.0072	0.047	3 970	186.59	-0.14
N_2	2.4	28	0.0857	0.558	690	385.02	-0.32
Total	4.225		0.1536			6225.52	-1.08

$$\widetilde{E_{x,CHM}} = 6225.52 - 8.1344 \times 298.15 \times 1.08034 = 3605.4(\frac{KJ}{kmole})$$

The average molar mass for combustion products =

$$\frac{mass\ of\ products}{number\ of\ products\ moles} = \frac{4.225}{0.1536} = 27.5\ kg/kmole$$

The chemical exergy of flue gases for unit wet bagasse=3605.4/27.5 = $131.1\frac{KJ}{kg}$

The total chemical exergy rate lost during the combustion of wet bagasse =3.4 MW,
and the total exergy for both chemical and physical lost during wet bagasse
combustion with flue gases= 3.4+14= 17.4 MW

3.15 EXERGY OF AIR REQUIRED FOR DRY BAGASSE COMBUSTION

In a bagasse fired boiler, the air-heater is normally situated before the economizer. The air temperature is raised from ambient to the under grate air temperature which is about 250°C when burning bagasse[38]. The amount of air required for full combustion of dry bagasse= 6.47(kg/kg of dry bagasse), therefore, the flow rate of the air required during dry bagasse burnets ($\dot{m}_a$) is 168.22 kg/s.

The only exergy considering atmospheric air is the physical exergy. The formula of physical exergy of gas given by T.J.Kotas when air assumed as ideal gas, equation 3.13 is applied to the atmospheric air as following

$$E_{x,air,dry} = \dot{m}_a \left[c_p(T - T_0) - T_0 \left(c_p ln\frac{T}{T_0} \right) \right]$$

Where:

$E_{x,air.dry} = exergy\ of\ air\ required\ for\ dry\ bagasse(MW)$

$m_{air} = air\ mass\ flow\ rate(\frac{kg}{s})$

C_p of air when the temperature is 523.15 k is 1.034 ($\frac{KJ}{Kg.K}$)

$$E_{x,air,d} = 168.22\ [1.034(523.15 - 298.15) - 298.15 \left(1.034\ ln\frac{523.15}{298.15} \right)]$$

$$E_{x,air,d} = 9.97\ MW$$

The chemical exergy of the atmospheric air is zero, therefore, the total exergy of air required for dry bagasse combustion $= E_{x,air,d,tot} = 9.97\ MW$

3.16 EXERGY OF AIR REQUIRED FOR WET BAGASSE COMBUSTION

The air required for wet bagasse combustion is 4.44 kg/kg of wet bagasse carried out in table 7.3 when 48% is excess air. Furthermore, the air flow rate during wet bagasse combustion is $= \dot{m}_a = 4.44 \times 26 = 115.44\ kg/s$ .exergy of air required for wet bagasse combustion calculated according to the equation 3.13 as following

$$E_{x,air,w} = \dot{m}_a[c_p(T - T_0) - T_0 \left(c_p ln\frac{T}{T_0} \right)]$$

Air assumed to be heated up to 250C° in air –heater component

$$E_{x,air,w} = 115.44[1.034 \times 225 - 298.15 \left(1.034 ln\frac{523.15}{298.15} \right)]$$

$$E_{x,air,w} = 6.84\ MW$$

3.17 ENTHALPY OF AIR REQUIRED FOR DRY & WET BAGASSE COMBUSTION

Enthalpy of air required for dry and wet bagasse combustion determined from materials properties table under Ideal-gas properties of air appendix (B) , the enthalpy of air considered when the temperature is 523.15 K^0(air temperature 250 C^0 when leaves air –heater) is 633.24 KJ/kg, therefore , the amount of energy received with the air required for dry bagasse combustion is $= 633.24 \times 168.22 = 106.52$ MW, for wet bagasse $=633.24 \times 115.44= 73.1$ MW

3.18 EXERGY OF Dry BAGASSE

Solid fuel like bagasse is conventionally is a thermal equilibrium with the environment, no reversible work and temperature difference occurs. The only exergy attendant bagasse is the chemical exergy. Solid and liquid industrial fuels are solutions of numerous chemical compounds, the ratio of chemical exergy of fuel (ε_f) to the net calorific value (NCV), equation 2.5 chapter two used for bagasse specific chemical exergy determination.

For dry organic substances contained in solid fossil fuels consisting usually of C, H, O and N in particular, includes wood: ; with the specific range of a mass ratio of oxygen to carbon as $(2.67 > o/c > 0.667)$ the following expression for ratio of chemical exergy to the net calorific value(the chemical constituent ratio) is obtained in terms of mass ratios[6].

$$\varphi_{dry} = \frac{1.0438 + 0.1882\frac{h}{c} - 0.2509\left(1 + 0.7256\frac{h}{c}\right) + 0.0383\frac{n}{c}}{1 - 0.3035\frac{o}{c}} \quad \dots\dots (3.14)$$

Where c, h, o and n are the mass fractions of C, H, O and N, respectively, from table 6.3 for dry bagasse $\frac{h}{c} = 0.1291$, $\frac{n}{c} = 0.0027$, and $\frac{o}{c} = 0.904$, from equation (14.3) therefore, the chemical constituent ratio for dry bagasse is $\varphi = 1.09394$.

For dry bagasse the net calorific value is ($NCV_{dry}=18\,071.77$ KJ/kg) and the specific exergy of dry bagasse calculated from equation 5.2 is:

$\varepsilon_{f=} 1.09394 \times 18\,071.77 = 19769.432 \text{KJ/kg}$

or $E_{X,f} = 19769.432 \times 26 = 514MW$

3.19 EXERGY OF WET BAGASSE

For moist fuel, the mass fraction of moisture in the fuel and enthalpy of water evaporation at standard temperature should be considered.

For using moist solid fuel ,T.J.Kotas [6] developed an expression to calculate the fuel exergy as following :

$$\varepsilon_f = [\text{NCV} + 2442\text{w}]\varphi_{dry} + 9\,417S \qquad (3.15)$$

For wet bagasse, the Net Calorific Value (NCV) carried out in table 5.3 is $=$ 7526.34 $KJ.Kg^{-1}$ the sulfur not appears in wet bagasse constituents presented in table 4.3 , the term of sulfur in equation 15.3 is neglected .Therefore, the specific exergy of wet bagasse given as:

$$\varepsilon_f = [\text{NCV} + 2442\text{w}]\varphi_{dry} = [7526.34 + 2442 \times 0.5]1.09394$$

$\varepsilon_f = 9569.065\ KJ.Kg^{-1}$ or $E_{x,f} = 248.79$ MW

3.20 ENTHALPY OF DRY BAGASSE COMBUSTION FLUE GASES

In Assalaya Sugar Factory, the air − reheater of the thermal power plant mounted just in the exit of flue gases passage that departure boiler. The average temperature of flue gases in air- reheater is 350 C^0, there is no economizer . Total enthalpy determined according to general form of perfects gas when temperature and specific heat capacities is known, used equation (3.16).

$$h = C_p T \qquad (3.16)$$

The enthalpy of dry bagasse analysis calculated and presented in table 3.14

Table 3.14: Enthalpy of dry bagasse flue gases

Products	Mass of flue gases (kg)	Relative Molar mass (kg/kmole)	Specific Heat capacity (kJ/kmole.k)	Enthalpy (kJ/kmol)	Enthalpy (kJ/kg)	Enthalpy (kJ)
CO_2	1.72	44	44.08	27468.45	624.28	1073.76
H_2O	0.54	18	34.78	21673.15	1204.06	650.19
N_2	5.15	28	30	18694.5	667.66	3438.45
SO_2	0.001	64	44.99	28035.52	438.055	0.7
Total						5163.1

Specific heat capacity: source T.J.Kotas Table D.1

The enthalpy of flue gases during dry bagasse combustion 5163.1 kJ / kg of dry bagasse .Therefore, the total enthalpy liberated with flue gases equal (5163.1×26 = 134.24 MW)

3.21 ENTHALPY OF WET BAGASSE COMBUSTION FLUE GASES

Enthalpy of wet bagasse flue gases also determined according to the equation 3.16 and summarized in table 3.15

Table 3.15: Enthalpy of wet bagasse flue gases

Products	Mass of flue gases (kg)	Relative Molar mass (kg/kmole)	Specific Heat capacity (kJ/kmole.k)	Enthalpy (kJ/kmol)	Enthalpy (kJ/kg)	Enthalpy (kJ)
CO_2	0.825	44	44.08	27468.45	624.28	515.03
H_2O	0.77	18	34.78	21673.15	1204.06	927.12
O_2	0.23	32	30.92	19267.78	602.12	138.49
N_2	2.4	28	30	18694.5	667.66	1602.38
Total	4.225					3183.02

The enthalpy of flue gases during wet bagasse combustion 3183.02 kJ / kg of dry bagasse .The total enthalpy liberated with flue gases is =3183.02×26 = 82.76 MW

3.22 HEAT ANALYSIS OF MAIN COMPONENTS FOR ASSALAYA THERMAL POWER PLANT

In order to improve the performance of a thermal power plant, it is necessary to analysis energy and exergy rate through the power plant components. Infact, component heat analysis enables engineers to take out reasons of degradation in order to reach the better operation point. Meanwhile, appropriate performance parameters can be indentified and enable engineers to correct measure to evaluate the power plant performance.

3.22.1 Boiler heat analysis for dry bagasse

Schematic diagram include combustion chamber and boiler taken as one unit for dry bagasse presented in figure 3.3 energy, exergy of stack gases, bagasse fuel, air required for bagasse combustion, feed water, and steam generation are simulated and estimated.
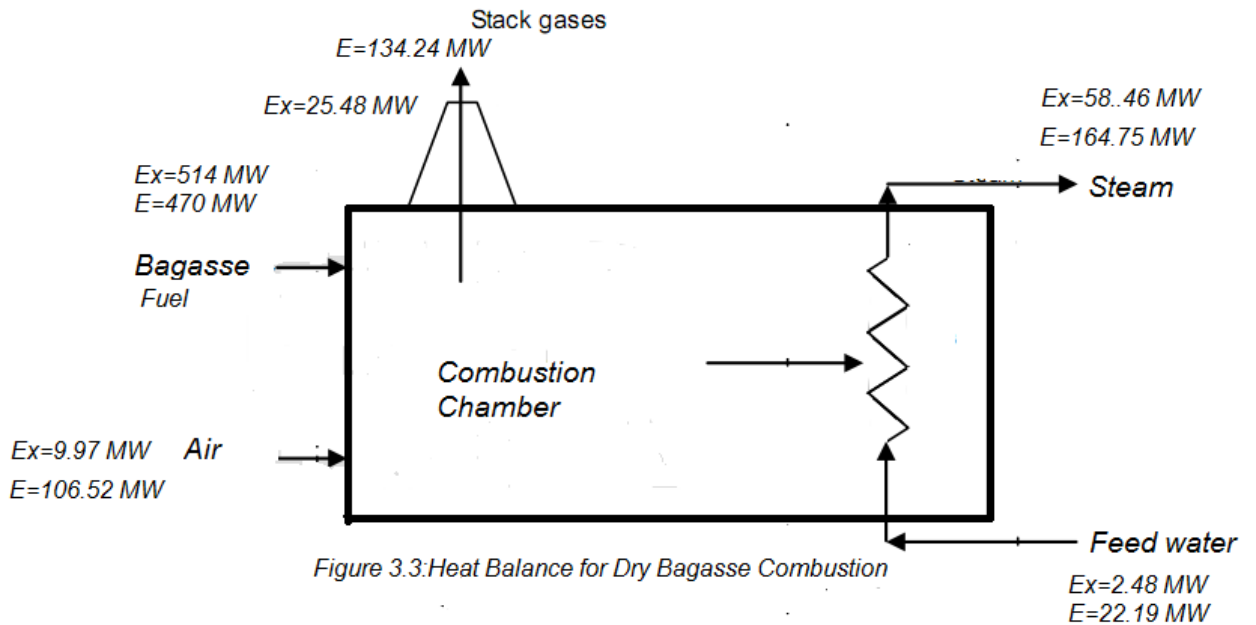
Figure 3.3:Heat Balance for Dry Bagasse Combustion

- From exergy heat balance, exergy destruction (consumed) in boiler during dry bagasee combustion is calculated as following :

$$[E_{x,f} + E_{x,a} - E_{x,fue\ gase} - (E_{x,1} - E_{x,14})]\alpha\beta\eta = E_{x,d} \qquad (3.17)$$

Where:-

$\alpha = coefficient\ taking\ into\ account\ unburnt\ solids = 0.98$
$\beta = coefficient\ of\ losses\ by\ radiation = 0.98$
$\eta = coefficient\ of\ incomplete\ combustion = 0.8$
$E_{x,f} = exergy\ of\ bagasse\ fuel\ (MW), E_{x,a} = combustion\ air\ exergy\ (MW)$

$E_{x,\text{flue gase}}$ = Production flue exegy (MW), $E_{x,1}$ = Steam Generation exegy (MW)

$E_{x,14} = Feed\ Water\ exergy(MW), E_{x,d} = exergy\ destruction\ (MW)$

$E_{x,d} = [514 + 9.97 - 25.48 - (58.46 - 2.48)]0.77 = 340.7MW$

The exergy destruction represents the exergy destroyed due to irreversibilities (entropy generation) within a system. The irreversibilities are caused by chemical reaction, heat transfer through a finite temperature difference, mixing of matter, unrestrained expansion, and friction. The exergy destruction is calculated with the aid of either:-

(a) An exergy balance formulated for the system

(b) The entropy generation ($E_d = T_0 S_{gen}$)

Exergy destruction calculated through this research used exergy balance formula, where exergy destruction is a function on system component efficiency [39].

The absolute value of exergy destruction in a component provides a measure of the significance of component irreversibilities from thermodynamics viewpoint[40].

- **Boiler energy efficiency**

Boiler is one of the high energy consumption equipment to provide hot water/steam .the key factors which involve affecting the boiler heat loss and efficiency are fuel calorific value, superheating surface area, excess air, feel water temperature, and exhaust gases temperature.

$$\eta = \frac{E_s}{E_f + E_a + E_w} = \frac{164.76}{470 + 106.52 + 22.19} = 27\%$$

- **Boiler exergy efficiency**

$$\eta_{x,B} = \frac{58.46}{514 + 9.97 + 2.48} = 11\%$$

3.22.2 Boiler heat analysis for wet bagasse

Figure 4.3:Heat Balance for Wet Bagasse Combustion
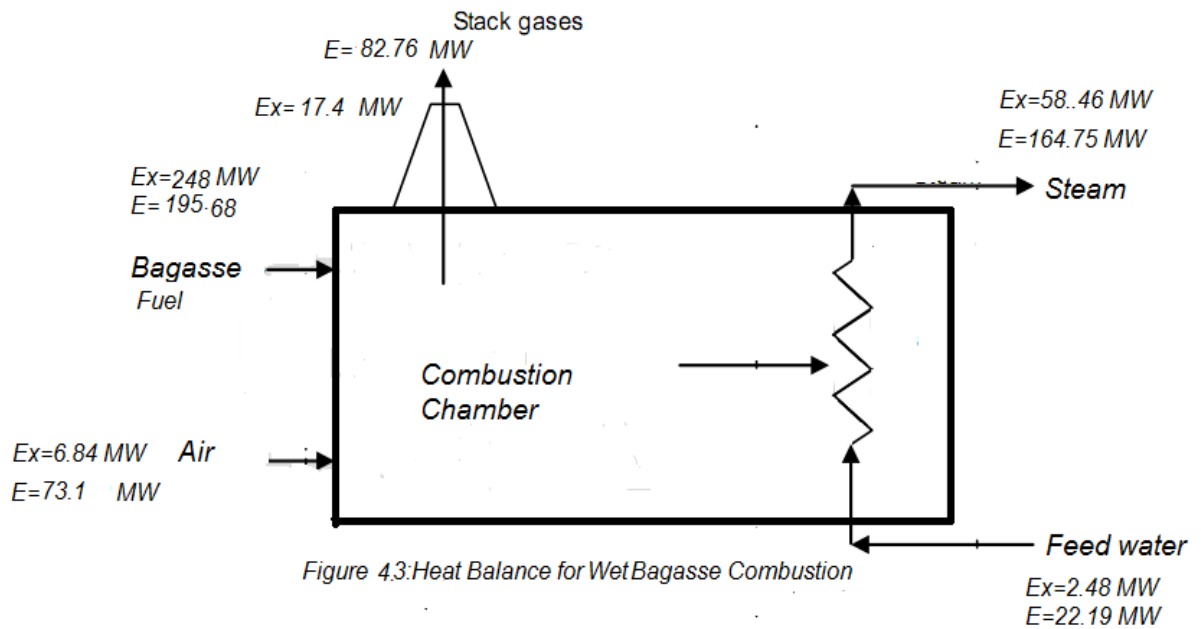
- **Exergy destruction in boiler due to the wet bagasse combustion**

$$[E_{x,f} + E_{x,a} - E_{x,p} - (E_{x,1} - E_{x,14})]\alpha\beta\eta = E_{x,d}$$

$$E_{x,d} = [284 + 6.84 - 17.4 - (58.64 - 2.48)]0.77 = 167.3 \; MW$$

- **Boiler energy efficiency**

$$\eta = \frac{E_s}{E_f + E_a + E_w} = \frac{164.76}{195.68 + 73.1 + 22.19} = 57\%$$

- **Boiler exergy efficiency**

$$\eta_{x,B} = \frac{58.46}{284 + 6.84 + 2.48} = 20\,\%$$

3.22.3 Heat analysis of turbine No.4

To measure how well a turbine is performing we can look at the isentropic efficiency. Isentropic efficiencies involve a comparison between the actual performance of a device and the performance that would be achieved under idealized circumstances. When calculating the isentropic efficiency heat to the surroundings is assumed to be zero (Turbine completely isolated). Isentropic

efficiencies involve a comparison between the actual performance of a device and the performance that would be achieved under idealized circumstances.
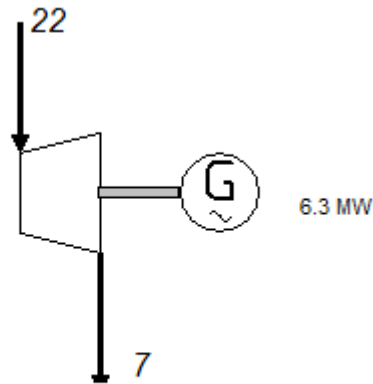
Figure 3.5 : Turbine 4 heat analysis
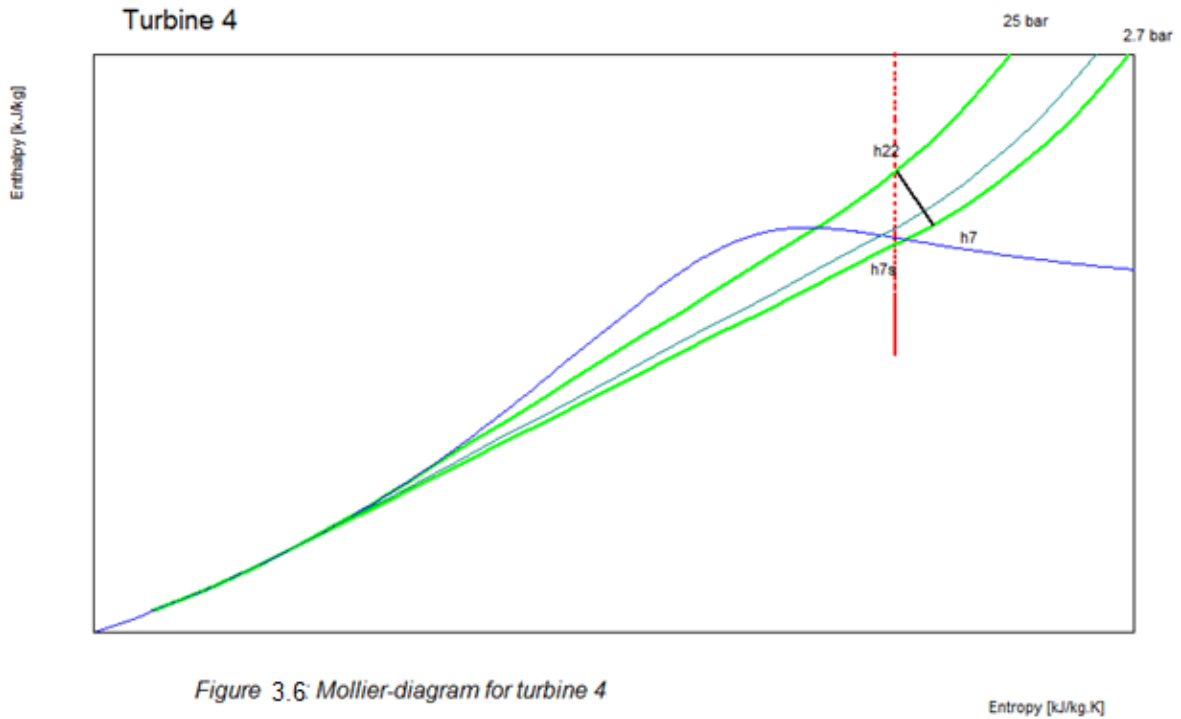
Figure 3.6: Mollier-diagram for turbine 4

- **The isentropic energy efficiency**

$$\eta = \frac{actual\ work}{isentropic\ work} = \frac{h_{22} - h_7}{h_{22} - h_{7s}} = \frac{3194 - 2819.2}{3194 - 2690} = 74\%$$

h_{7s} isentropic enthalpy determined from mollier – diagram for turbine figure 3.6 and h_{22}, h_7 taken from main flow data for pipes in Assalaya sugar Factory Thermal Power Plant table 2.3

- **Exergy destruction**

$$E_{x,d} = E_{x,in} - E_{x,out} = 20.48 - 18.45 = 2.03\ MW$$

- **The exergy efficiency :**

$$\eta_{x,T} = \frac{outcoming\ exergy}{incoming\ exergy} = \frac{E_{x,7} + E_{x,G}}{E_{x,22}} = \frac{18.45}{20.48} = 90\%$$

3.22.4 Heat analysis of turbine No. 5
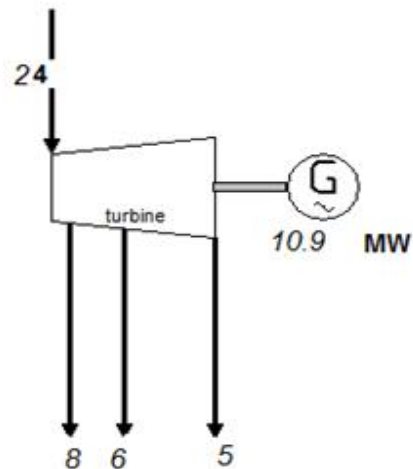
Figure 3.7 : Turbine 5 heat analysis
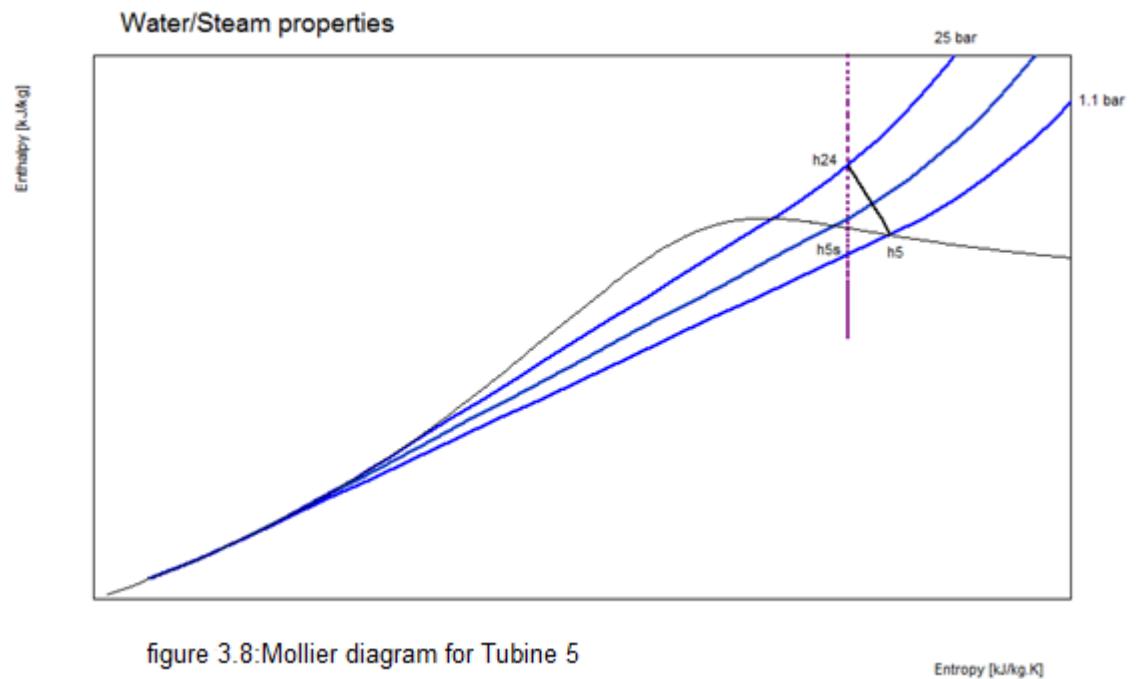
figure 3.8:Mollier diagram for Tubine 5

- **The isentropic energy efficiency :**

$$\eta = \frac{actual\ work}{isentropic\ work} = \frac{h_{24} - h_5}{h_{24} - h_{5s}} = \frac{3194 - 2685}{3194 - 2530} = 76.65\%$$

- **Exergy destruction:**

$$E_{x,d} = E_{x,in} - E_{x,out} = 22.75 - 22.75 = 0\ MW$$

- **The exergy efficiency :**

$$\eta_{x,T} = \frac{outcoming\ exergy}{incoming\ exergy} = \frac{E_{x,8} + E_{x,6} + E_{x,5} + E_{x,G}}{E_{x,24}}$$

$$\eta_{x,T} = \frac{1.39 + 4.59 + 5.92 + 10.9}{22.75} = 100\%$$

3.22.5 Heat analysis of crushing mills No.3

The determination of the power consumed by a mill is rather complex because a number of factors enter into it[16].

(1) Power consumed by compression of the bagasse

(2) Power consumed in friction between the shafts and bearings of the rollers

(3) Power consumed by friction between bagasse and trashplate

(4) Power consumed by friction of scrapers and toe of the trashplate against the rollers.

(5) Power consumed in driving the intermediate carriers

(6) Power absorbed in the gearing

Furthermore, these components of the power themselves depend on certain factors rather difficult to measure of estimate exactly, such as variety of cane (variation of fiber weight),state of the friction surfaces ,quality and regularity of lubrication ,adjustment of settings and of the trashplate .Owing to the impossibility of taking into account all these factors ,there is no point in seeking great precision in the calculation of power for milling.E.Hugot [16] ensured that the power required for milling in practice may differ appreciably from the mean power figures which derive theoretically ,this difference may be as much as 20 - 25 % of the normal value furnished by the formula .

Assalaya thermal power plant drives six crushing mill turbine. The total power assumed to be required for driving the crushing mill is 5.5 MW.
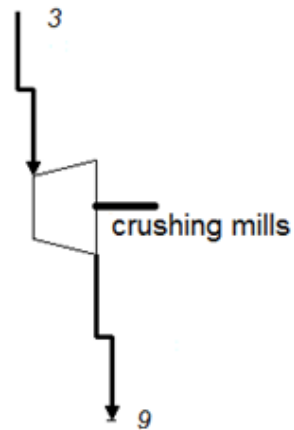
Figure 3.9: Heat Analysis of Crushing Mills

Water/Steam properties
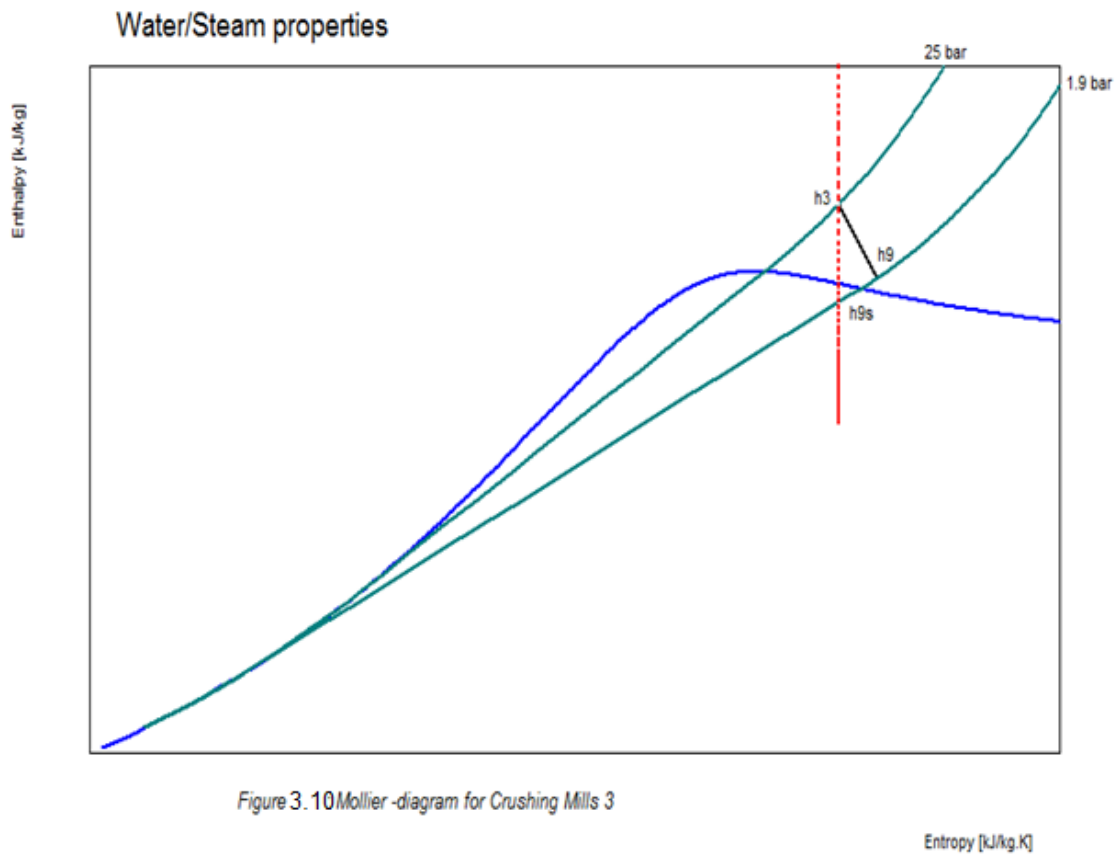
Figure 3.10 Mollier -diagram for Crushing Mills 3

- **The isentropic energy efficiency :**

$$\eta = \frac{actual\ work}{isentropic\ work} = \frac{h_3 - h_9}{h_3 - h_{9s}} = \frac{3194 - 2769}{3194 - 2630} = 75\%$$

- **Exergy destruction :**
- $E_{x,d} = E_{x,in} - E_{x,out} = 15.22 - 13.87 = 1.35\ MW$

- **The exergy efficiency :**

$$\eta_{x,Ch} = \frac{outcoming\ exergy}{incoming\ exergy} = \frac{E_{x,9}}{E_{x,3}} = \frac{8.17 + 5.5}{15.22} = 90\%$$

3.22.6 Heat analysis of condenser

Condenser of Assalaya thermal power plant is a shell and tube heat exchanger. Shell and Tube design is one of the most common types of exchangers used in heat transfer typically used in applications when a process requires large amounts of fluid to be heated or cooled , also offer a large surface area and thus high heat transfer efficiency.
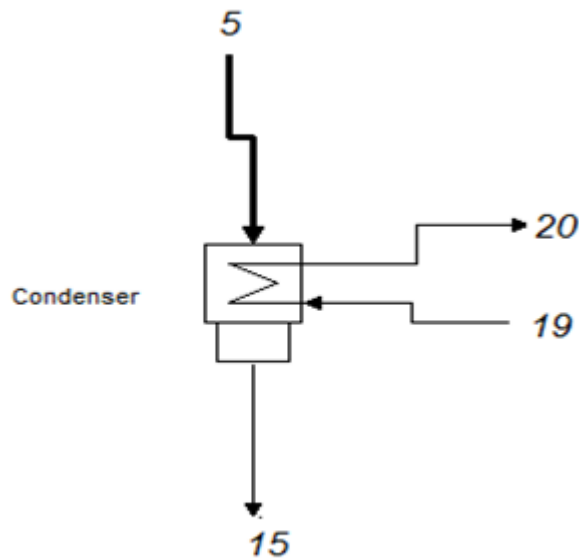
Figure 3.11: Heat analysis in condenser

- **Energy efficiency**

$$\eta = \frac{h_{15} + h_{20}}{h_5 + h_{19}} = \frac{196.74 + 147.14}{2685 + 118.18} = 12\%$$

- **Exergy destruction**

$$E_{x,d} = E_{x,in} - E_{x,out} = (5.02 + 8.08) - (0.12 + 8.34) = 4.64 \; MW$$

- **Exergy efficiency**

$$\eta_{x,C} = \frac{E_{x,15} + E_{x,20}}{E_{x,5} + E_{x,19}} = \frac{8.46}{13.1} = 64\%$$

3.22.7 Heat analysis of deaerator

A deaerator is a device that is widely used for the removal of oxygen and other dissolved gases from the feedwater to steam-generating boilers. In particular, dissolved oxygen in boiler feedwater will cause serious corrosion damage in steam systems by attaching to the walls of metal piping and other metallic equipment and forming rust. The deaerators is the steam generating systems of most thermal power plants use low pressure steam obtained from an extraction point in their steam turbine system. Deaerator heated feed water close to saturation temperature (105 C^0) with minimum pressure drop .Deaeration done by spraying the boiler feed water over multiple layers of trays designed to provide large contact area between the liquid surface and Deaerator steam .Feed water heats up to saturation temperature and dissolved gases are released from the feed water through the vent valve.
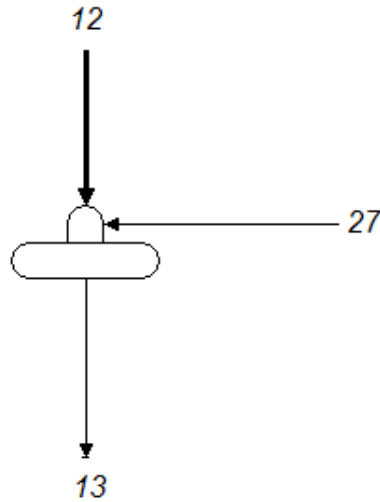
Figure 3.12:Heat analysis in deaerator

- **Energy efficiency**

$$\eta = \frac{h_{13}}{h_{12} + h_{27}} = \frac{427.031}{2816.8 + 251.21} = 14\%$$

- **Exergy destruction**

$$E_{x,d} = E_{x,in} - E_{x,out} = 1.7 + 0.87 - 2.28 = 0.29 \ MW$$

- **Exergy efficiency**

$$\eta_{x,C} = \frac{E_{x,13}}{E_{x,12} + E_{x,27}} = \frac{2.28}{2.57} = 88.7\%$$

3.22.8 Heat analysis of pumps No. (11, 14, &21)

The vast majority of pumps in the study area, or sugar factory in general are centrifugal pumps, with direct coupled electric motors.
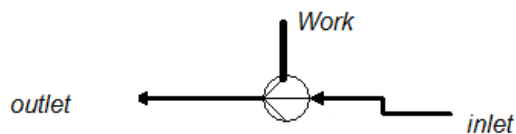
Figure 3.13 Heat Analaysis of Pumps

- **The Energy Efficiency**

$$\eta = \frac{E_{out} - E_{in}}{work}$$

- **The Exergy destruction &Efficiency**

$$E_{x,d} = E_{x,out}$$

$$\eta_{x,pump} = \frac{E_x}{}$$

Tabl1 3.16: Heat destruction and Efficiencies of Pumps

Component Name	Number	Exergy Destruction (MW)	Energy Efficiency(η)%	Exergy Efficiency ($\eta_{x,pump}$)%
Pump	11	- 0.602	18.7	25
Pump	14	- 0.205	73	78
Pump	21	- 0.045	14.5	42

3.22.9 Energy balance of sink/source
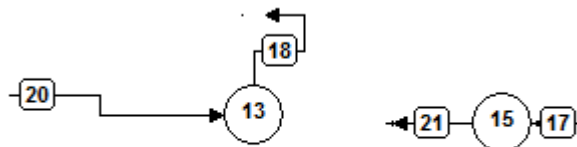
Figure **3.14** : thermal Flow of Sink/ Source

Table 3.17: Exergy Destruction & Exergy Efficiency of Sink /Source

Component Name	Number	Exergy Destruction (MW)	Exergy Efficiency(η)%
Sink/Sou.	13	1.01	88
Hot well	15	1.34	37

69

3.22.10 Energy balance of nodes

Table 3.18: Exergy Destruction & Exergy Efficiency of Nodes

Component Name	Number	Exergy Destruction (MW)	Exergy Efficiency $(\eta)\%$
Node	7	0.02	100
Node	8	0.2	99
Node	9	3.45	80.5
Node	12	0.242	83

3.23 HEAT OF EVAPORATION PER UNIT OF BAGASSE

Heat of evaporation is defined as the amount of heat required to convert a unit mass of liquid (water) at its boiling point into vapor without an increase in temperature, per unit of bagasse. E.Hugot ensure that the heat transferred to steam per unit bagasse is direct proportional to fuel net calorific value and inversely proportion to water moisture content ,and flue gases sensible heat.

3.23.1 Sensible heat of flue gases

The heat of the water vapour passing with the gases to the chimney is called sensible heat of flue gases, such as a function on heat transferred to steam.

The sensible heat lost with flue gases obtained by E.Hugot [16] as:

$$Q = [(1 - w)(1.4m - 0.13) + 0.5]T \tag{3.18}$$

For dry bagasse, no moisture and no excess air required for complete combustion[16], therefore, $w = 0, m = 1$,equation (3.18) becomes:-

$$Q = 1.77T \ \frac{kcal}{kg} \tag{3.19}$$

Flue gases leave boiler in 350 C^0

$$Q = 1.77 \times 350 = 619.5 \frac{kcal}{kg} = 2591.94 \frac{kJ}{kg}$$

For wet bagasse, which contained 50% water moisture, ratio of weight of air used to the theoretically necessary air m= 1.48, and flue gases temperature is 350 C^0, the sensible heat is calculated according to equation 3.18 is:-

70

$$\therefore Q = 2154.1 \frac{kJ}{kg}$$

3.23.2 Heat for steam generation

A general formula derived by E.Hugot [16] used to evaluate quantity of heat required to transferred to the steam, given as:-

$$M_v = (NCV -$$

Where:

$\alpha = 0.975$, $\beta = 0.97$, $\gamma = 0.95$ for spreader –stoker furnaces ,where Assalaya Sugar Factory Thermal Power Plant one of this types.

Sucrose(S) destroyed by microorganisms and thus disappears in a short time in storage[41] ,for dry bagasse moisture and sucrose assumed to be equal zero.

Therefore, heat for steam generation when used dry bagasse is:

$$M_v = 13909.$$

But for wet bagasse contained 50 % moisture, and 2% sucrose, the heat transferred to the steam is:-

$$M_v = 5092.7$$

CHAPTER IV

RESULTS & DISCUSSION

4.1 THERMODYNAMICS PROPERTIES FLOW CHART

The specific exergy flow chart which presented in table 3.2, carried- out from the theoretical analysis of governing equations compared to the specific exergy flow chart of the advanced simulation software program (temp-cycle release 5), introduced in table 4.1. A comparison of the two methods presented in figure 4.1 .no contrasts clearly appear between the two values. Similarly, the specific energy flow for the theoretical analysis and simulation presented in figure 2.4, generally, the simulation and analysis for energy, exergy flow are likeliness, and this reflects accuracy of the procedures and validate of data.

Figure 4.1:Analytical & Simulation of Exergy flow in power plant

Table 4.1: Energy, Exergy flow tempo-cycle simulation

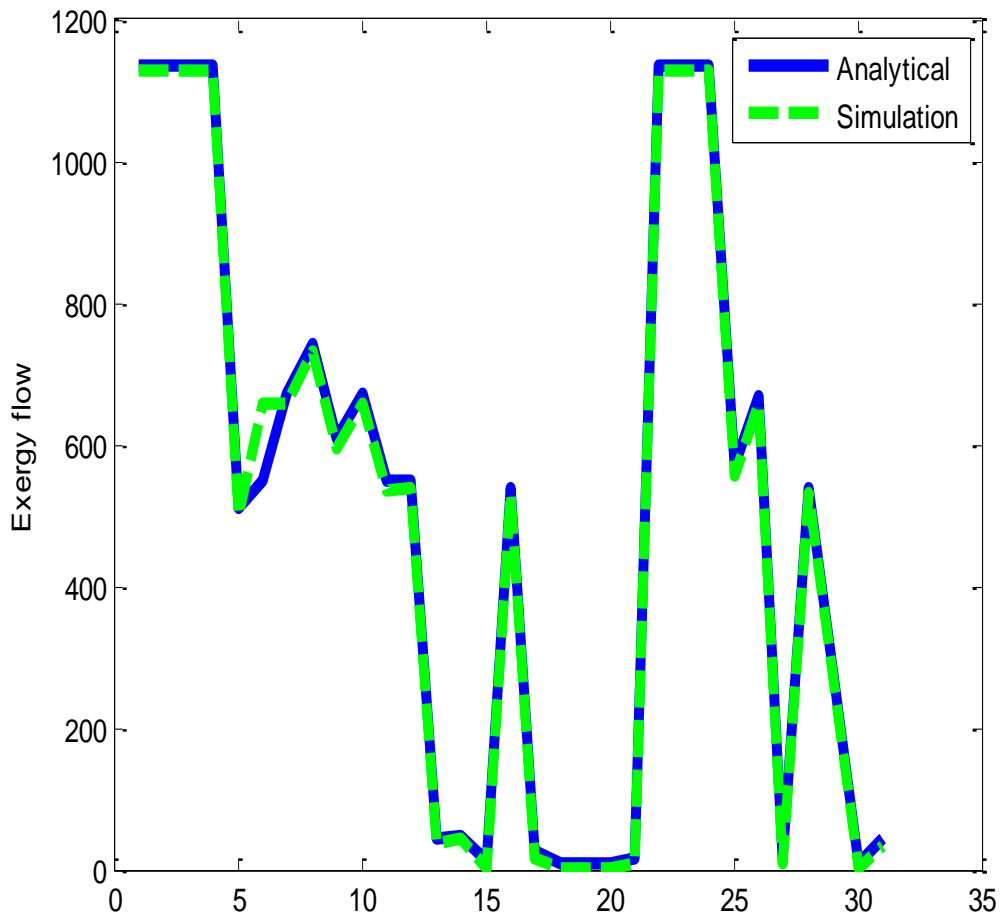| Pipe no.	Medium	Mass flow [kg/s]	Mole flow [kmol/s]	Volume flow [m3/s]	Pressure [bar]	Temperature [°C]	Enthalpy [kJ/kg]	Entropy [kJ/kg.K]	Exergy [kJ/kg]	Quality [%]
1	WATERSTM	51.583	2.863	5.9850	25.00	380.00	3195.07	6.9491	1127.76	100.00
				5.9850	25.00	380.00	3195.07	6.9491	1127.76	100.00
2	WATERSTM	13.430	0.745	1.5582	25.00	380.00	3195.07	6.9491	1127.76	100.00
				1.5582	25.00	380.00	3195.07	6.9491	1127.76	100.00
3	WATERSTM	13.430	0.745	1.5582	25.00	380.00	3195.07	6.9491	1127.76	100.00
				1.5582	25.00	380.00	3195.07	6.9491	1127.76	100.00
4	WATERSTM	18.075	1.003	2.0972	25.00	380.00	3195.07	6.9491	1127.76	100.00
				2.0972	25.00	380.00	3195.07	6.9491	1127.76	100.00
5	WATERSTM	9.858	0.547	15.395	1.100	105.00	2684.81	7.3418	500.43	100.00
				15.395	1.100	105.00	2684.81	7.3418	500.43	100.00
6	WATERSTM	8.340	0.463	6.2461	2.700	173.12	2812.14	7.2439	656.93	100.00
				6.2461	2.700	173.12	2812.14	7.2439	656.93	100.00
7	WATERSTM	18.075	1.003	13.664	2.700	177.00	2820.18	7.2618	659.62	100.00
				13.664	2.700	177.00	2820.18	7.2618	659.62	100.00
8	WATERSTM	1.880	0.104	1.0177	4.000	205.65	2872.83	7.1972	731.53	100.00
				3.7022	1.100	198.90	2872.83	7.7862	555.93	100.00
9	WATERSTM	13.430	0.745	13.582	1.900	150.00	2769.86	7.3060	596.13	100.00
				23.450	1.100	146.99	2769.86	7.5551	521.86	100.00
10	WATERSTM	26.415	1.466	19.910	2.700	175.78	2817.64	7.2562	658.77	100.00
				19.910	2.700	175.78	2817.64	7.2562	658.77	100.00
11	WATERSTM	22.858	1.269	42.285	1.100	171.03	2817.64	7.6657	536.67	100.00
				42.285	1.100	171.03	2817.64	7.6657	536.67	100.00
12	WATERSTM	3.557	0.197	6.5793	1.100	171.03	2817.64	7.6657	536.67	100.00
				6.5793	1.100	171.03	2817.64	7.6657	536.67	100.00
13	WATERSTM	51.583	2.863	0.053918	1.100	102.29	428.77	1.3328	35.95	0.00
				0.053918	1.100	102.29	428.77	1.3328	35.95	0.00
14	WATERSTM	51.583	2.863	0.053843	40.00	102.98	434.58	1.3375	40.37	0.00
				0.053843	40.00	102.98	434.58	1.3375	40.37	0.00
15	WATERSTM	9.858	0.547	0.0099671	1.100	47.75	200.00	0.6745	3.46	0.00
				0.0099671	1.100	47.75	200.00	0.6745	3.46	0.00
16	WATERSTM	38.168	2.119	69.439	1.100	163.92	2803.55	7.6337	532.11	100.00
				69.439	1.100	163.92	2803.55	7.6337	532.11	100.00
17	WATERSTM	48.026	2.666	0.049329	1.100	77.10	322.83	1.0408	17.09	0.00
				0.049329	1.100	77.10	322.83	1.0408	17.09	0.00
18	WATERSTM	1188.149	65.953	1.1926	1.000	28.00	117.47	0.4091	0.06	0.00
				1.1926	1.000	28.00	117.47	0.4091	0.06	0.00
19	WATERSTM	1188.149	65.953	1.1922	10.00	28.07	118.60	0.4098	0.97	0.00
				1.1922	10.00	28.07	118.60	0.4098	0.97	0.00
20	WATERSTM	1188.149	65.953	1.1942	7.000	33.07	139.22	0.4787	1.05	0.00
				1.1942	6.000	33.09	139.22	0.4790	0.95	0.00
21	WATERSTM	48.026	2.666	0.048846	1.100	60.00	251.23	0.8312	7.98	0.00
				0.048846	1.100	60.00	251.23	0.8312	7.98	0.00
22	WATERSTM	18.075	1.003	2.0972	25.00	380.00	3195.07	6.9491	1127.76	100.00
				2.0972	25.00	380.00	3195.07	6.9491	1127.76	100.00
23	WATERSTM	20.078	1.115	2.3296	25.00	380.00	3195.07	6.9491	1127.76	100.00
				2.3296	25.00	380.00	3195.07	6.9491	1127.76	100.00
24	WATERSTM	20.078	1.115	2.3296	25.00	380.00	3195.07	6.9491	1127.76	100.00
				2.3296	25.00	380.00	3195.07	6.9491	1127.76	100.00
25	WATERSTM	1.880	0.104	3.7022	1.100	198.90	2872.83	7.7862	555.93	100.00
				3.7022	1.100	198.90	2872.83	7.7862	555.93	100.00
26	WATERSTM	8.340	0.463	6.2461	2.700	173.12	2812.14	7.2439	656.93	100.00
				6.2461	2.700	173.12	2812.14	7.2439	656.93	100.00
27	WATERSTM	48.026	2.666	0.048837	6.100	60.05	251.87	0.8315	8.50	0.00
				0.048850	1.100	60.15	251.87	0.8331	8.04	0.00

74
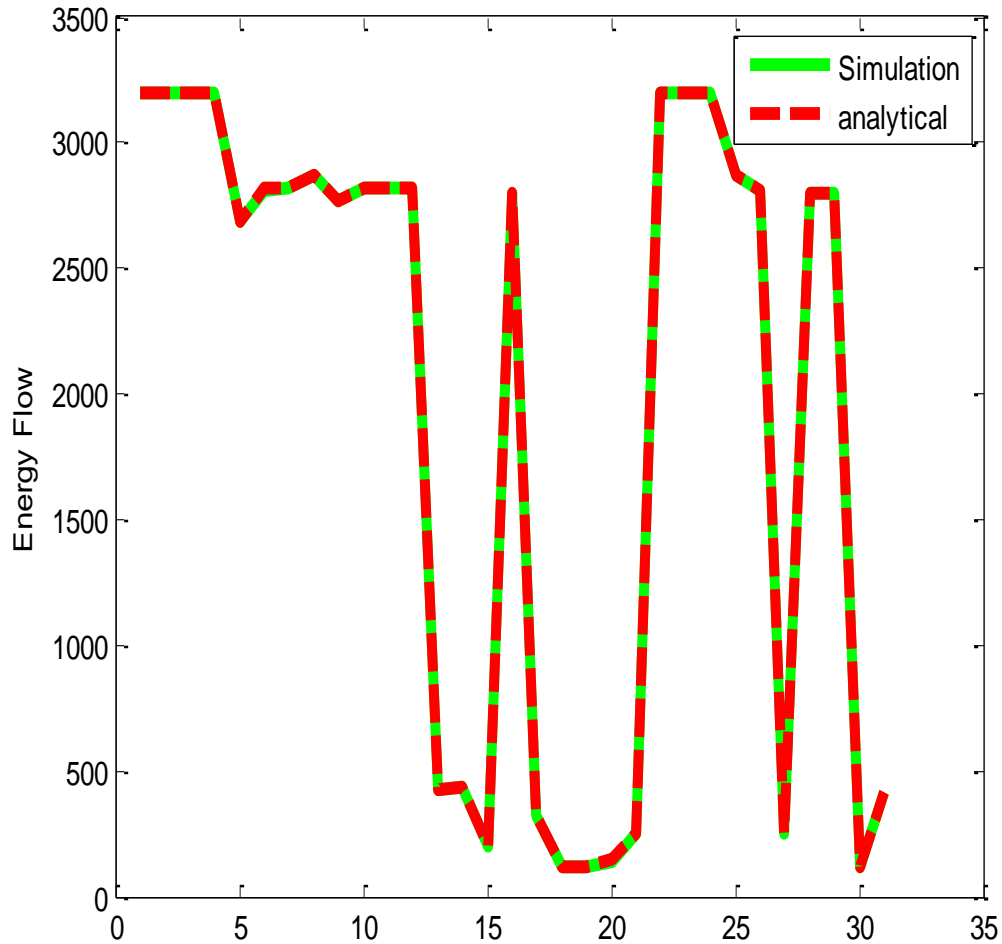
Figure 4.2:Analytical & Simulation of energy flow in power plant

4.2 ENERGY, EXERGY EFFICIENCIES & DESTRUCTION

The aim of the study is to identify the location and magnitude of useful energy and exergy lost during the process at various components of Assalaya thermal power plant. The losses at various components are calculated using the energy and exergy heat balance equations (2.13- 2.21) and Advanced Simulation Programs for Total Energy Systems (Asimptote) Cycle – Tempo Program was used for the theoretical data analysis approach to check validation and verification. Table 4.2 displayed the energy, exergy efficiencies and destruction of Assalaya thermal power plant main components.

Table 4.2: Energy, Exergy efficiencies and Destruction of the mains cycle components

No.	Components	Exergy Destruction (MW)	Exergy Efficiency %	Energy Efficiency %
1	Boiler for dry bagasse	340.7	11	27
1	Boiler for wet bagasse	167.3	20	57
3	Crushing Mill Turbines	1.35	91	75
4	Turbine 6.3 MW	2.03	90	74
5	Turbine 10.9 M	0	100	76.65
6	Condenser	4.64	64	12
10	Deaerator	0.29	88.7	14
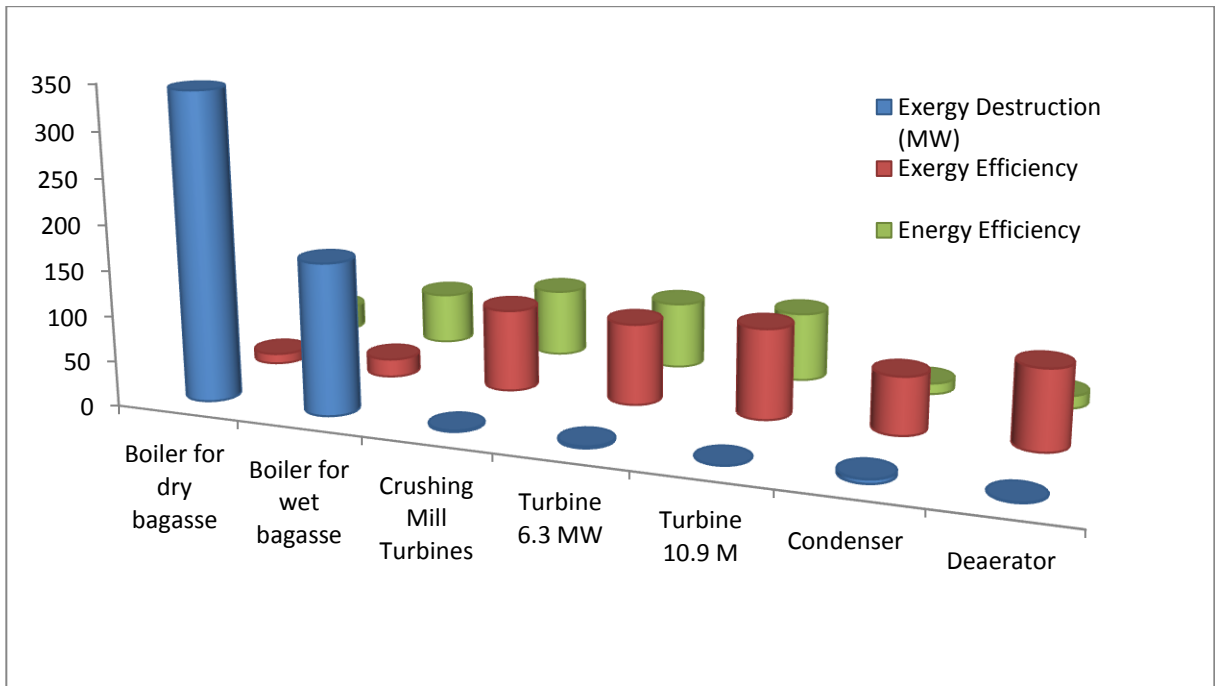
Figure 4.3: Energy, Exergy efficiencies and Destruction of the mains cycle components

The major of exergy lost due to irreversibility and other sources is significantly occur in dry bagasse boiler is 340.7 MW, where it forms 97% of the total exergy lost in power plant system, and it is the dominant over all components of the power cycle, which evaluated from exergy balance equation, when 26 kg/s of dry bagasse was burned. But 167.3 MW that forms 95% of exergy lost in the same process during wet bagasse combustion. Clearly, significant improvement exists in combustion chamber and boiler system. The energy efficiency for Turbine10.9 MW indicated 100% if the generator develops 10.9 MW of electricity and no energy lost

occurring through the turbine. It can be deduced from thermal power plant components heat analysis, that turbines have highest efficiencies while condenser has lowest energy efficiency .Otherwise, turbine 10.9 MW has highest exergy efficiency and boilers has the lowest exergy efficiency.

The heat required for steam generation when used dry bagasse is defined according to formula derived by E.Hugot [16],equation 20.3 is M_v=13909.08 kJ/kg 0f dry bagasse and for wet bagasse M_v= 5092.76 KJ/kg of wet bagasse ,the net heat added to the system through boiler when pressure and temperature (25 bar, 380 ^{0}C) is 3194 − 442.79(feed water enthalpy) = 2751.21 KJ/kg of steam. The ratio of superheat steam generated to the dry bagasse combustion (evaporation coefficient) carried out as following:

$$\sigma = \frac{13909.08}{2751.21} = 5.05 (Dry\ bagasse)$$

For wet bagasse, where w = 0.5, m = 1.48, T = 350 ^{0}C and Sucrose percentage in wet bagasse, S = 0.02, the evaporation coefficient is carried out as following:-

$$\sigma = \frac{5092.76}{2751.21} = 1.85\ \text{(Wet bagasse)}$$

The vapour produced per unit weight of bagasse which known as Evaporation Coefficient lies within the range of 2 − 2.7 for wet bagasse [16].In Assalaya Sugar Factory thermal power plant ,the evaporation coefficient for dry and wet bagasse combustion is 5.05 and 1.85 respectively. The evaporation coefficient for wet bagasse is inversely proportional to bagasse moisture contains, presented in Fig 4.4 To get evaporation coefficient equivalent to the E.Hugot[16] range, bagasse must be contained moisture ranged 45% - 35% ,erection of bagasse dryer to decrease bagasse moisture is very compulsory to reach E.Hugot evaporation coefficient range.

Heat required for steam generation from dry bagasse according to E.Hugot [16] formula, equation (20.3) is 361.64 MW and the heat required for the same amount of bagasse carried out used the heat balance method for dry bagasse combustion illustrated in Figure 3.3 is 362.28 MW, when takes into account the coefficients for unburnt bagasse ,losses of radiation , and incomplete combustion is 0.78 .

Otherwise, the heat required for steam generation from wet bagasse according to E.Hugot formula is 134.41 MW and from heat balance method for wet bagasse combustion illustrated in figure 4.3 is 162.7 MW
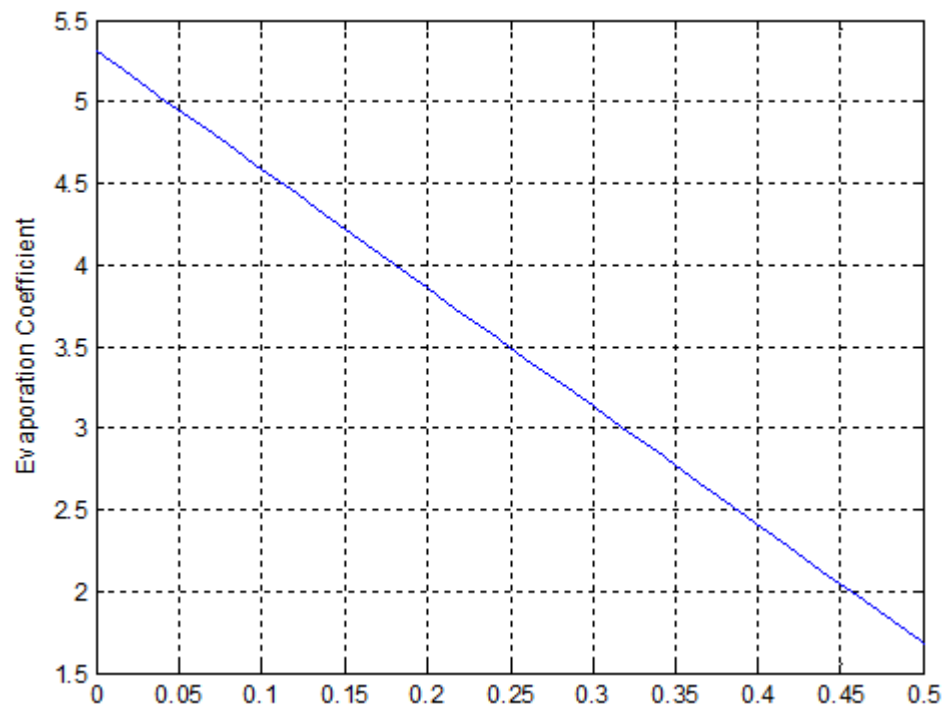
Figure 4.4: Evaporation coefficient Vs Bagasse Moisture Content

There is no large difference between the values of heat required for steam generation for both E.Hugot formula and heat balance method for dry bagasse combustion. , On the other hand, the contrast is clearly observed between the value of heat required for steam generation used E.Hugot formula and heat balance method for wet bagasse combustion.

The overall efficiencies of Assalaya Thermal Power Plant which defined as a heat ratio between a net heat power delivered to system to the amount of heat power absorbed. Produced from theoretical data analysis is represented in table 2.4, the energy efficiency for gross and net is 15.8 % and 14.8% respectively, similarly, exergy efficiency is 39.6 % for gross and 37.7 % for net. Also, system efficiency carried out from tempo simulation software presented in table 4.4 no large contrast between efficiencies value appeared.

Generally, the energy efficiency of a conventional thermal power stations, considered salable energy produced as a percent of the heating value of the fuel consumed, is typically 33% to 48%.The energy efficiency of Assalaya obviously very small if compared to the conventional thermal power stations ,because the energy of a thermal power station not utilized only on the electric power production ,therefore ,a significant amount of energy disposed on the sugar production process. If the energy of the sugar production process (71.53 MW) is taken into account, the energy efficiency increased for gross and net as 65%, 48.9 % respectively.

Table (4.3): System efficiency of theoretical analysis

Type of Power	Apparatus		Energy (kW)	Totals (kW)	Exergy (kW)	Total (kW)
Absorbed	Boiler		142560	142560	55980	55980
Delivered Gross Power	Generator	2	6500		6500	
	Generator	1	10900		10900	
	Turbine	3	5500	22900	5500	22900
Aux. Power Consumption	Pump	11	8000		800	
	Pump	14	1000		1000	
	Pump	21	0	1800	0	1800
Delivered Net Power				21100		21100
Efficiencies	Gross		15.8 %			39.6 %
	Net		14.8 %			37.7 %

Table (4.4): System efficiency from Tempo- Simulation Program

delivered	No.	Apparatus	Type	Energy [kW]	Totals [kW]	Exergy [kW]	Totals [kW]
Absorbed	1	Boiler	1	141892.16		55984.90	
power					141892.16		55984.90
Delivered	2	Generator	G	6640.67		6640.67	
gross power	1	Generator	G	8653.02		8653.02	
	3	Turbine	3	5710.58		5710.58	
					21004.28		21004.28
Aux. power	11	Pump	8	847.79		847.79	
consumption	14	Pump	8	1005.90		1005.90	
	21	Pump	8	40.34		40.34	
					1894.03		1894.03
Delivered							
net power					19110.25		19110.25
Efficiencies	gross			14.803 %		37.518 %	
	net			13.468 %		34.135 %	

4.3 OPTIMUM OPERATION & SYSTEM EFFICIENCY IMPROVEMENT

Boiler and sugar production processes are considered as a highest energy lost components for Assalaya Sugar Factory Thermal Power Plant,suggestions for improving boiler efficiency and eliminated leakage in sugar production most be necessary. Decrease of cooling water temperature difference in condenser not affecting the gross efficiencies but reduced the net efficiencies. Change in environment temperature have a limitted effect on power plant efficiency . Sugar production treatments   process need steam under low pressure and temperature range as $120 - 150 \, C^0$,clearly , if accuracy monitoring and observation of sugar production process thermodynamics parameters taken into account ,sufficient energy can be saved.

If pressure of steam exhausted from crushing mill increased from 1.9 bar to 2 bar and temperature dropped from 147 ^{0}C to 130 ^{0}C , also the steam exhaust from turbine 4 dropped from 2.7 bar to 1.5 bar and temperature from 177 ^{0}C to 120 ^{0}C .Therefore,the gross efficiency jumped from 14.8%   for energy and 37.5% for exergy to 17.2% for energy and 43.6% for exergy efficiency.Similarly , the net efficiency changed from 13.47% for energy and 34.13% for exergy to 15.9% and 40.3% for energy and exergy respectively, optimum and enhance of system

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efficiencies presented on table 4.5 and the thermodynamics properties of steam flow showed on figure 4.5

Table 4.5: Optimum system efficiencies

delivered	No.	Apparatus	Type	Energy [kW]	Totals [kW]	Exergy [kW]	Totals [kW]
Absorbed	1	Boiler	1	141350.28		55771.09	
power					141350.28		55771.09
Delivered	2	Generator	G	8568.57		8568.57	
gross power	1	Generator	G	9474.82		9474.82	
	3	Turbine	3	6282.73		6282.73	
					24326.12		24326.12
Aux. power	11	Pump	8	846.73		846.73	
consumption	14	Pump	8	1005.38		1005.38	
	21	Pump	8	0.00		0.00	
					1852.12		1852.12
Delivered							
net power					22474.00		22474.00
Efficiencies	gross			17.210 %		43.618 %	
	net			15.900 %		40.297 %	
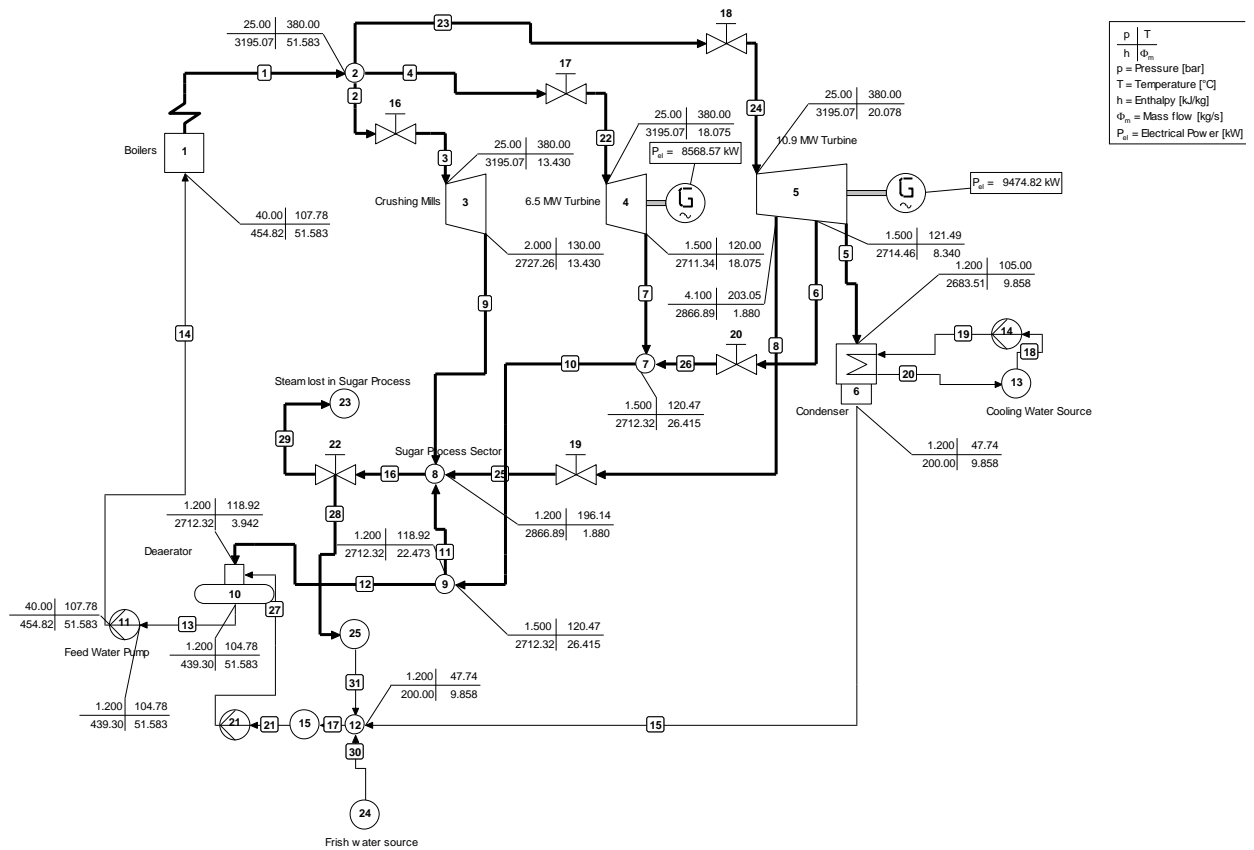
Figure 5-4 :Schematic diagram of Assalaya Sugar Factory Thermal Power Plant- Optimum Operation condition

CHAPTER V
CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

1. Energy, exergy analysis and improvement operation is carried out for bagasse thermal power plant (Assalaya Sugar Factory Thermal Power Plant is the case study) which considered as one of the main source of renewable energy and have made a significant contribution to the reduction of greenhouse gas emissions[42].Studies of thermal power plant use bagasse as direct fuel is very limited ,on the other hand ,full attention for energy experts efforts given to the thermal power plant use gas, coal ,and heavy oil as fuel for steam generation.

2. Through this research, energy, exergy has been analysized to identify the amount and location of energy, exergy lost or occurring on the power plant component.

3. Performance of bagasse combustion, with or without the moisture content is discussed broadly.

4. Chemical and physical constituent of wet and dry bagasse was defined according to the Ebager[27]thermogravimetric analyzer studies ,slightly variation on values appear when compared to the different authors.

5. Gross and net calorific values of bagasse (wet & dry) assessed through laboratory analysis or expert's calculation formulas were presented.

6. Stoichiometric quantities method was followed for identify mass of air required to perform a complete combustion for both wet and dry bagasse.

7. The vapour produced per unit weight of bagasse which known as Evaporation Coefficient lies within the range of 2 – 2.7 for wet [16].In Assalaya Sugar Factory thermal power plant ,the evaporation coefficient for dry and wet bagasse combustion is 5.05 and 1.85 respectively.

8. The evaporation coefficient for wet bagasse is inversely proportional to bagasse moisture contains.

9.To get evaporation coefficient equivalent to the E.Hugot[16] range, bagasse must be contained moisture ranged 45% - 35% ,erection of bagasse dryer to decrease bagasse moisture is very compulsory to reach E.Hugot evaporation coefficient range.

10. The amount of heat required for steam generation from dry bagasse combustion according to E.Hugot formula is 361.64 MW and the heat required for steam generation for similar bagasse carried out through the heat balance method is 362.28 MW. Otherwise, the heat for steam generation from wet bagasse combustion according to E.Hugot formula is 134.41 MW and for the similar bagasse used heat balance method is 162.7 MW. There is no large difference between the values of heat required for steam generation for both E.Hugot formula and heat balance for dry bagasse combustion. On the other hand, the contrast is clearly observed between the values of heat required for steam generation used E.Hugot formula and heat balance method for wet bagasse combustion. Interpretation of more accurate method to evaluate the wet bagasse heat required for steam generation, abandoned and recommended for other researchers.

11. Katmar Software for engineering and risk analysis is a water steam properties calculator which was used for water and steam properties determination in this research. This program developed to calculates the physical properties of water steam in all popular units; it replaced printed steam tables and eliminates the need to interpolate between data points.

12. The specific enthalpy and entropy values for each state point in a plant system are calculated, through which energy, exergy efficiencies of plant components were defined.

13. In order to analyzed the energy and exergy performances of this power plant, thermodynamic model and simulation was developed used Cycle – Tempo release 5, Software Packages of Advanced Simulation Programs for Total Energy Systems (Asimptote). Cycle – Tempo was developed jointly by Delft University of technology and by TNO, the Dutch institute for applied research .Since 2011,it is further developed and supported by Asimptote in close cooperation with the original developers within the propulsion and Power group of the TU Delft ,constantly expanding Cycle Tempo's capabilities.   Cycle – Tempo is flow sheeting for the thermodynamic analysis and optimization of energy conversion systems, also,

considered as one of the few software packages that allows for exergy analysis. It has been around for more than a decade and has a large user community, including major energy companies' consultancy firms and research and development institutes.

14. The main feature of Cycle –Tempo is the calculation of all relevant mass and energy flows in the system .It has a particularly robust and efficient computational method, which means that you can depend on it to quickly obtain a reliable solution even in the most demanding situation. Also,can perform exergy analysis which provides insight into the exergy flows and losses within subsystems.

15. The major of exergy lost due to irreversibility and other sources is significantly occur in dry bagasse boiler is 340.7 MW, where it forms 97% of the total exergy lost in power plant system, and it is the dominant over all components of the power cycle, but 167.3 MW that forms 95% of exergy lost in boiler for the same process during wet bagasse combustion.

16. It can be deduced from thermal power plant components heat analysis, that turbines have highest energy efficiency while condenser has lowest energy efficiency .

17. Turbine5 (10.9 MW) has highest exergy efficiency and boilers has the lowest exergy efficiency.

18. The overall efficiencies of Assalaya Thermal Power Plant which defined as a heat ratio between a net heat power delivered to system to the amount of heat power absorbed, produced from theoretical data analysis is illustrated that the energy efficiency for gross and net is 15.8 % and 14.8% respectively, similarly, exergy efficiency is 39.6 % for gross and 37.7 % for net .

19. The energy efficiency of Assalaya thermal power plant obviously very small if compared to the conventional thermal power stations, because the energy of a thermal power station not utilized only on the electric power production, therefore, a significant amount of heat disposal in the sugar production process.

20. If the energy of the sugar production process (71.53 MW) is taken into account, the energy efficiency increased for gross and net as 65%, 48.9 % respectively.

 21. Decreased of pressure or inceased when temperature is constant through the boiler has limited effect on the overall system efficincies.

22. Decrease of cooling water temperature difference in condeser not affecting the gross efficiencies but reduced the net efficiencies.

23. Environment temperature variation have alimitted effect on power plant efficiency .

24. Sugar production treatments   process need steam under low pressure and temperature range as $120 - 150 \, C^0$,clearly , if accuracy monotoring and observation of sugar production process thermodynamics prameters taken into account ,sufficient energy can be saved. For improving thermal system performance,

25. If pressure of steam exthausted from crushing mill increased from 1.9 bar to 2 bar and temperature droped from $147 \,^0C$ to $130 \,^0C$, addition to the steam exthaust from turbine 4 droped from 2.7 bar to 1.5 bar and temperature from $177 \,^0C$ to $120 \,^0C$,therefore,the gross efficiency jumped from 14.8%   for energy and 37.5% for exergy to 17.2% for energy and 43.6% for exergy.Similary , the net efficiency changed from 13.47% for energy and 34.13% for exergy to 15.9% and 40.3% for energy and exergy respectivily.

5.2 RECOMMENDATIONS

Studies of bagasse performance and energy, exergy fluxes of Assalaya thermal power plant involved various indicators should be taken into account to improve the power plant efficiency :-

➢ Wet bagasse contained considerable water moisture ,must be burned during combustion and takes heat from the combustion of fuel gets evaporated and finally come out to chimney as a superheated steam .Thus ,heat is lost by sensible heating and evaporation of water. The largest portion of heat in Assalaya thermal power plant lost occurs through the stack gas. High temperature of exhaust gas (350 ^{0}C) when leaves the economizer, this can be utilized as bagasse dryer.

➢ The major energy losses occur in boiler , Fouling, scaling, and soot which the main character of bagasse build up on heat transfer surfaces of boilers act as insulators and lead to reduced heat transfer. This results in lower heat transfer to the water in the pipes of the boiler.M.C.Barma et al [43]confirmed that 0.8 mm of soot layer extremely case 69% reduction in heat transfer. The effective ways to deal with this problem are accurate periodically monitoring of ash fouling and soot-blowing.

➢ Significant amount of heat disposal in the sugar production processes (71.53 MW).Perfect control should be take place on specific steam extracted for sugar production processes such as clarification, crystallization, and drying dramatically increase the thermal power plant efficiency.

➢ The reference environment state(dead state) temperature variation when pressure is constant have a limited effects on the results of exergy

➢ The heat required for steam generation that carried out through heat balance method for wet bagasse combustion not matching with the heat required for steam generation used E.Hugot formula .The variation between the two methods need exclusive materializes to show the accurate method, therefore, this issue leaves for interesting wet bagasse combustion researchers.

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Appendix A: Standard Chemical Exergy

Table A.2 Standard enthalpy of devaluation and standard chemical exergy of chemical elements. Reproduced from Ref [6.31], by permission. ($T^0 = 298.15$ K, $P^{00} = 1.013\ 25$ bar.)

		Enthalpy of devaluation		Chemical exergy		
Chemical element	Standard state of the element	Reference substance	Standard enthalpy of devaluation, h_d^0/[kJ/kmol]	Reference substance	Concentration of reference substance in standard environment	Standard chemical exergy, ε^0/[kJ/kmol]
1	2	3	4	5	6	7
Ag	s	AgCl, s	46 260	$AgCl_2^-$, i	2.7×10^{-9} (w)	73 700
Al	s	Al_2SiO_5, s sillimanite	927 800	Al_2SiO_5, s sillimanite	2×10^{-3} (c)	887 890
Ar	g	Ar, g	0	Ar, g	0.907 (a)	11 690
As	s	—	—	$HAsO_4^{2-}$, i	1.5×10^{-8} (w)	477 040
Au	s	Au, s	0	$AuCl_2^-$, i	5.8×10^{-11} (w)	18 900
B	s	—	—	$H_2BO_3^-$, i	4.6×10^{-6} (w)	615 920
Ba	s, II	$BaSO_4$, s, barite	741 640	Ba^{2+}, i	5×10^{-8} (w)	760 050
Bi	s	Bi_2O_3, s	288 680	Bi_2O_3, s	7×10^{-10} (c)	271 370
Br_2	l	—	—	Br^-, i	6.5×10^{-5} (w)	91 770
C	s, graphite	CO_2, g	393 780	CO_2, g	0.03 (a)	410 820
Ca	s, II	$CaCO_3$, s, calcite	813 910	Ca^{2+}, i	4×10^{-4} (w)	717 400
Cd	s, α	$CdCO_3$, s	354 410	Cd^{2+}, i	5×10^{-11} (w)	290 920
Cl_2	g	NaCl, s	161 710	Cl^-, i	19×10^{-3} (w)	117 520
Co	s, III	Co_3O_4, s	293 080	Co^{2+}, i	9×10^{-11} (w)	260 520
Cr	s	Cr_2O_3, s	564 590	Cr_2O_3, s	4×10^{-7} (c)	538 610
Cs	s	CsCl, s	352 480	Cs^+, i	2×10^{-9} (w)	408 530
Cu	s	$CuCO_3$, s	201 590	Cu^{2+}, i	5×10^{-9} (w)	134 400
D_2	g	D_2O, g	249 370	D_2O, g	0.00014 (a)	266 220
F_2	g	CaF_2, s	401 500	F^-, i	1.4×10^{-6} (w)	448 820
Fe	s	Fe_2O_3, s, hematite	411 350	Fe_2O_3, s	2.7×10^{-4} (c)	377 740

Table A.3 Standard enthalpy of devaluation and standard chemical exergy of inorganic substances. Reproduced from Ref [6.31], by permission. ($T^0 = 298.15$ K, $P^0 = 1.013\ 25$ bar.)

Substance	State*	Relative molecular mass	Standard enthalpy of devaluation, $\bar{h}_0^0$/[kJ/kmol]	Standard chemical exergy, $\bar{e}^0$/[kJ/kmol]
1	2	3	4	5
Ag	s	107.870	46 260	73 730
Ag_2CO_3	s	275.749	− 20 180	121 940
AgCl	s	143.323	0	23 420
AgF	s	126.868	43 950	120 810
$AgNO_3$	s	169.875	− 76 960	46 580
Ag_2O	s	231.739	61 910	64 540
Ag_2O_2	s	247.739	67 620	179 036
Ag_2S	s, α	247.804	785 280	714 060
Ag_2SO_4	s	311.802	103 250	144 220
Al	s	26.981 5	927 800	887 890
Al_4C_3	s	143.959	4 763 080	4 661 880
$AlCl_3$	s	133.340 5	474 510	426 940
Al_2O_3	s, corundum	101.961 2	184 690	204 270
$Al_2O_3 \cdot H_2O$	s	119.976 5	125 520	199 450
$Al_2O_3 \cdot 3H_2O$	s, gibbsite	156.007 2	12 160	209 210
Al_2S_3	s	150.155	3 520 230	3 079 540
$Al_2(SO_4)_3$	s	342.148	592 060	502 100
Al_2SiO_5	s, andalusite	162.046	28 030	45 940
Al_2SiO_5	s, cyanite	162.046	25 940	49 200
Al_2SiO_5	s, sillimanite	162.046	0	15 400
Ar	g	39.948	0	11 690
Au	s	196.967	0	18 920
AuCl	s	232.42	46 100	63 410
$AuCl_3$	s	303.326	124 070	152 110
AuF_3	s	253.962	253 490	437 260
Au_2O_3	s	441.932	− 80 810	121 550
Ba	s, II	137.34	741 640	760 050
$BaCO_3$	s, II, witherite	197.35	− 84 190	37 170
$BaCl_2$	s	208.25	42 710	63 610
BaF_2	s	175.34	− 58 050	61 470
BaO	s	153.34	183 120	244 880
BaO_2	s	169.34	111 530	175 770
$Ba(OH)_2$	s	171.36	36 590	145 520
BaS	s	169.40	1 022 420	896 670
$BaSO_3$	s	217.40	282 750	257 450
$BaSO_4$	s, barite	233.40	0	13 470
Bi	s	208.980	288 680	271 370
BiO	s	224.979	81 240	92 440
Bi_2O_3	s	465.958	0	52 260
Bi_2S_3	s	514.152	2 567 720	2 165 480
C	s, graphite	12.011 15	393 780	410 820
C	s, diamond	12.011 15	395 680	413 690
CCl_4	l	153.823	584 270	583 180
CO	g	28.010 5	283 150	275 430
CO_2	g	44.009 5	0	20 140

Formula	State	M		
CS_2	l	76.139	1 932 410	1 673 670
Ca	s, II	40.08	813 930	717 400
CaC_2	s	64.10	1 538 670	1 471 210
$CaCO_3$	s, calcite	100.09	0	5 050
$CaCO_3$	s, aragonite	100.09	− 170	6 100
$CaCl_2$	s	110.99	180 130	84 910
$CaCl_2 \cdot H_2O$	s	129.00	107 700	63 610
$CaFe_2O_4$	s	215.77	104 600	56 480
$Ca_2Fe_2O_5$	s	271.85	324 680	213 620
$Ca(NO_3)_2$	s	164.089 8	− 123 290	− 11 970
$Ca(NO_3)_2 \cdot 2H_2O$	s	200.120 5	− 241 790	− 17 020
$Ca(NO_3)_2 \cdot H_2O$	s	218.135 8	− 289 290	− 8 740
$Ca(NO_3)_2 \cdot 4H_2O$	s	236.151 2	− 349 290	− 8 870
CaO	s	56.08	177 940	119 620
$CaO \cdot Al_2O_3$	s	158.04	388 690	326 780
$2CaO \cdot Al_2O_3$	s	214.12	105 760	339 540
$4CaO \cdot Al_2O_3$	s	326.28	—	485 420
$12CaO \cdot 7Al_2O_3$	s	1 386.68	3 362 640	2 211 220
$Ca(OH)_2$	s	74.09	68 660	62 500
$Ca_3(PO_4)_2$	s, α	310.18	0	31 910
CaS	s	72.14	1 055 750	838 880
$CaSO_4$	s, anhydrite	136.14	104 950	4 300
$CaSO_4 \cdot \frac{1}{2}H_2O$	s, α	145.15	83 260	4 350
$CaSO_4 \cdot \frac{1}{2}H_2O$	s, β	145.15	85 350	5 310
$CaSO_4 \cdot 2H_2O$	s, gypsum	172.17	0	2 760
$CaSiO_3$	s	116.16	93 780	27 590
Ca_2SiO_4	s	172.24	235 290	116 680
Ca_3SiO_5	s	228.32	419 240	250 770
Cd	s, α	112.40	354 410	290 920
$CdCO_3$	s	172.41	0	36 960
$CdCl_2$	s	183.31	126 750	65 810
CdO	s	128.40	99 600	65 980
$Cd(OH)_2$	s	146.41	38 480	61 370
CdS	s	144.46	934 550	749 050
$CdSO_4$	s	208.46	152 200	81 290
$CdSO_4 \cdot H_2O$	s	226.48	88 520	63 070
Cl_2	g	70.906	161 710	117 520
Cl	g	35.453	201 850	163 940
Co	s, III	58.933 2	293 080	260 520
Co_3C	s	188.810 75	1 312 790	1 222 110
$CoCO_3$	s	118.942 6	− 36 200	29 630
$CoCl_2$	s	129.839	129 060	103 800
CoO	s	74.932 6	53 600	51 070
Co_3O_4	s	240.797 2	0	37 560
$Co(OH)_2$	s	92.947 9	− 14 230	47 120
$Co(OH)_3$	s	109.955 3	− 83 310	27 240
CoS	s	90.997	933 090	765 580
Co_2S_3	s	214.058	2 590 640	2 108 250
$CoSO_4$	s	154.995	148 900	103 220
Cr	s	51.996	564 590	539 260
Cr_3C_2	s	180.010	2 393 410	2 348 290
Cr_4C	s	219.995	2 583 480	2 494 900
Cr_7C_3	s	400.005	4 955 530	4 819 010
$CrCl_2$	s	122.902	330 400	306 000
$CrCl_3$	s	158.355	243 610	221 120

HF	g	20.006 4	52 960	71 840
HNO$_3$	l	63.012 9	− 52 330	45 650
H$_2$O	l	18.015 34	− 44 030	3 120
H$_2$O	g	18.015 34	0	11 710
H$_3$PO$_4$	s	98.001 3	− 75 360	98 850
H$_2$S	g	34.080	946 420	804 770
H$_2$SO$_4$	l	98.077	154 720	161 010
He	g	4.002 6	0	30 290
Hg	l	200.59	68 560	122 700
HgCO$_3$	s	260.60	− 89 390	193 550
HgCl$_2$	s	271.50	0	63 100
Hg$_2$Cl$_2$	s	472.09	33 720	153 740
HgO	s, red	216.59	− 22 210	64 240
HgS	s, red	232.65	734 940	679 430
HgSO$_4$	s	296.65	88 500	150 580
Hg$_2$SO$_4$	s	497.24	119 210	234 880
K	s	39.102	355 330	371 520
K$_2$CO$_3$	s	138.213	− 42 450	90 110
KCl	s	74.555	0	21 390
KClO$_4$	s	138.553	2 430	125 900
KF	s	58.100	− 6 880	59 760
KMnO$_4$	s	158.038	62 680	148 840
KNO$_3$	s	101.106 9	− 137 380	− 15 290
K$_2$O	s	94.203	348 820	425 540
KOH	s	56.109	50 200	101 320
K$_2$S	s	110.268	1 016 560	928 230
K$_2$SO$_3$	s	158.266	317 780	384 910
K$_2$SO$_4$	s, II	174.266	590	38 470
K$_2$SiO$_3$	s	154.288	1 308 010	1 565 320
Kr	g	83.80	0	34 280
Li	s	6.939	328 200	396 170
Li$_2$CO$_3$	s	73.887	− 166 250	77 180
LiCl	s	42.392	0	70 160
LiNO$_3$	s	68.934	− 154 450	12 700
Li$_2$O	s	29.877	60 200	233 460
LiOH	s	23.946	− 38 350	75 620
Li$_2$SO$_4$	s	109.940	− 54 380	76 520
Mg	s	24.312	719 920	626 710
MgCO$_3$	s	84.321	0	13 700
MgCl$_2$	s	95.218	239 370	151 860
MgFe$_2$O$_4$	s	200.004	76 640	38 230
MgO	s	40.311	117 690	59 170
Mg(OH)$_2$	s	58.327	36 610	33 830
Mg(NO$_3$)$_2$	s	148.321 8	− 69 680	50 950
Mg(NO$_3$)$_2 \cdot$ 6H$_2$O	s	256.413 8	− 440 400	29 400
MgS	s	56.376	1 097 000	875 550
MgSO$_3$	s	104.374	438 730	305 400
MgSO$_4$	s	120.374	165 430	67 480
MgSiO$_3$	s	100.396	81 430	25 060
Mg$_2$SiO$_4$	s	140.708	255 810	140 770
Mg$_2$TiO$_4$	s	160.52	185 980	92 200
Mn	s, α, IV	54.938 1	521 260	483 240
Mn$_3$C	s, II	176.825 45	1 953 370	1 856 770
MnCO$_3$	s	114.947 5	19 480	35 360
MnCl$_2$	s	125.844	200 230	159 340

Substance	State[a]	Relative molecular mass	Standard enthalpy of devaluation, $\bar{k}_d^0$/[kJ/kmol]	Standard chemical exergy, $\bar{e}^0$/[kJ/kmol]
1	2	3	4	5
CrO_3	s	99.994	−14 850	42 910
Cr_2O_3	s	151.990	0	36 510
Cs	s	132.905	352 480	408 530
CsCl	s	168.358	0	62 850
$CsNO_3$	s	194.910	−141 980	22 310
Cs_2O	s	281.809	387 180	544 370
CsOH	s	149.912	66 520	164 090
Cs_2S	s	297.874	1 089 990	1 091 020
Cs_2SO_4	s	361.872	8 590	123 020
Cu	s	63.54	201 590	134 400
$CuCO_3$	s	123.55	0	33 210
CuCl	s	98.99	146 370	77 050
$CuCl_2$	s	134.45	157 310	120 450
$CuFe_2O_4$	s	239.23	36 580	22 790
CuO	s	79.54	46 260	6 590
Cu_2O	s	143.08	236 380	123 500
$Cu(OH)_2$	s	97.55	−5 230	19 770
CuS	s	95.60	877 600	668 020
Cu_2S	s, II	159.14	1 048 210	773 000
$CuSO_4$	s	159.60	155 800	80 940
Cu_2SO_4	s	223.14	377 490	222 450
D_2	g	4.029 46	249 370	266 220
D_2O	g	20.028 86	0	33 450
D_2O	l	20.028 86	−45 430	24 520
F_2	g	37.996 8	401 500	448 820
Fe	s	55.847	411 350	377 740
Fe_3C	s, cementite	179.552	1 648 760	1 558 570
$FeCO_3$	s, siderite	115.856	56 950	120 410
$FeCl_2$	s	126.753	231 840	193 130
$FeCl_3$	s	162.206	248 630	225 600
$FeCr_2O_4$	s	223.837	108 990	133 490
FeO	s	71.846	140 800	133 750
Fe_2O_3	s, hematite	159.692	0	20 370
Fe_3O_4	s, magnetite	231.539	116 170	126 960
$Fe(OH)_3$	s	106.869	−50 450	46 530
FeS	s, α	87.911	1 040 810	879 000
FeS	s, β	87.911	1 046 540	890 180
FeS_2	s, pyrite	119.975	1 682 480	1 447 410
$FeSO_4$	s	151.909	212 740	170 240
FeSi	s	83.933	1 190 140	1 099 080
$FeSiO_3$	s	131.931	115 690	111 260
Fe_2SiO_4	s	203.778	243 670	228 310
$FeTiO_3$	s	151.75	86 870	99 530
H_2	g	2.015 94	242 000	238 490
H	g	1.007 97	360 860	322 410
HCl	g	36.461	109 490	85 950