Exergy Analysis Of 19 MW Power Plant

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Major Project

Submitted in partial fulfillment of the requirements

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Master of Technology in Mechanical Engineering

(Thermal Engineering)

By

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Declaration

This is to certify that

(i) The thesis comprises my original work towards the degree of Master of Technology in Thermal Engineering at Nirma University and has not been submitted elsewhere for a degree.

(ii) Due acknowledgement has been made in the text to all other material used.

Chirag P Patel

Undertaking for Originality of the Work

I, Chirag P Patel, Roll.No. 12MMET31, give undertaking that the major project entitled **" Exergy analysis of 19 MW power plant "** submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in Mechanical Engineering (Thermal Engineering), of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

Signature of student

Date :

Place : Ahmedabad

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Certificate

This is to certify that the Major Project Report entitled **"EXERGY ANALYSIS OF 19MW POWER PLANT"** submitted by **Chirag P Patel (12MMET31)**. Towards the partial fulfillment of the requirements for the awards of Degree of **Master of Technology in Mechanical Engineering (Thermal Engineering)** at **Institute of Technology, Nirma University** is the record of work carried out by him under our supervision and guidance. In our opinion submitted work has reached a level required for being accepted for examination. The result embodied in this major project, to the best of our knowledge, has not been submitted to any other University or Institution for award of any degree.

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Abstract

Energy sector is one of the important areas in the economic development of any country meeting the grooving energy demand at acceptable cost in various sectors like industries, transport, etc. is the challenge to the energy planner.

The energy is generally evaluated on the basis of quantity in energy analysis. However, the exergy analysis evaluates the energy on the basis of quantity as well as the quality. The aim of the exergy analysis is to identify the magnitudes and to find out the locations of real energy losses in process, to improve the systems process or component.

Energy resources and their utilization intimately relate to sustainable development. In attaining sustainable development, increasing the energy efficiency of processes utilizing sustainable energy resources plays an important role. A sustainable energy system may be regarded as a cost efficient reliable and environmentally friendly energy system that effectively utilizes local resources and networks. Exergy analysis has been widely used in the design, simulation and performance evaluation of energy systems.

The present project deals with an exergy analysis performed on an operating 19 MW power plant in ESSAR LTD, HAZIRA. The exergy losses occurred in the various subsystems of the plant and their components have been calculated using the mass, energy and exergy balance equations. The distribution of the exergy losses in several plant components has been assessed to locate the process irreversibility. The first law efficiency (energy efficiency) and the second law efficiency (exergy efficiency) of the plant have also been calculated.

The real losses of energy which has a scope for the improvement are given as maximum exergy losses that occurred in the boiler.

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NOMENCLATURE

SYMBOL	DESCRIPTION
A	Availability, kJ
u	Specific internal energy, kJ/Sec
$\triangle$s	Change in Entropy, kJ/kgK
s	Specific Entropy, kJ/kgK
h	Specific Enthalpy , kJ/kg
T	Temperature, K
T_0	Environmental Temperature, K
Q	Heat Supplied, kJ
q	Specific Heat, kJ/kg
W	Shaft Work, Net Work, kJ/s
E	Energy, kJ/s
E_X	Exergy, kJ/s
E_{XK}	Kinetic Exergy, kJ/kg
E_{XP}	Potential Exergy, kJ/kg
m	Specific mass flow rate of Fluid,kg/s
C_P	Specific Heat At Constant Pressure, kJ/kmol-K
I	Irreversibility
R	Universal gas constant, kJ/kgK

Chapter 1

INTRODUCTION

1.1 INTRODUCTION

Energy sector plays a vital role in our country's economic development and it is expected to be even more significant in the coming years in order to improve the quality of life of our growing population. Availability of cheap power sectors plays a very important role in prosperity of industry, agricultural and transportation.

A multidimensional approach is required keeping in view the various economic options available through effective demand management. Therefore, augmentation of power, energy conservation and efficient use of energy has been viewed as a major supply option. Efficiency improvements have been initiated in major energy intensive industries. Even though there is a degree of awareness in India today than even before regarding the importance of power augmentation, energy conservation measures and its efficient use, the results achieved so far are significant. The primary objective of energy efficiency measures in the industry is to lower energy costs by reducing the need for purchased energy or by using least cost energy resources.

Energy, being a conserved quantity, is not a scare resources thus energy does not represent the potential to cause the change and is not the commodity of interest for evaluating process efficiency. In order to analyses process irreversibility it is essential to reply on the second law thermodynamics. The second law constrains the direction in which any energy transformation can occur. So the second law analysis or exergy analysis which is relatively a new technique , when applied to a whole plant tells how much of the usable work potential or exergy, supplied as the input to the system has been consumed by the process or the plant. The loss of exergy or irreversibility as sometimes called provides a generally applicable quantitative measure of process inefficiency. The feasibility of reduction of losses, so estimated can only be found out by economic analysis.

However, wider application of exergy method of analysis can lead to substantially reduced rate in the use of natural resources and pollution of the environment. As energy analysis is based on the first law of thermodynamics, it has some inherent limitations like not accounting for properties of the system environment, or degradation of the energy quality through dissipative processes. An energy analysis does not characterize the irreversibility of processes within the system. Exergy is the maximum work that can be obtained from the system, when its state is brought to the reference or dead state (standard atmospheric conditions). Exergy analysis is based on the second law of thermodynamics. This paper will examine a detailed exergy analysis of a thermal power plant, in order to assess the distribution of irreversibility and losses, which contribute to loss of efficiency in system performance.

Analysis of multi component plant based on this concept indicates the total plant irreversibility distribution amongst the plant component, heat load analysis for inlet air cooling and pinpointing those parameters contributing most to overall plant inefficiency. Such an estimate only will help in planning the future course of the energy system design and power augmentation. It is with this view the present topic is chosen for the dissertation.

1.2 ENERGY ANALYSIS

One of the earliest procedures in the evaluation of power cycle using energy analysis was due to J. K. Salibury[1],[2]. Significant feature of this method, generally known as heat deviation method, where to use the analytic description of the turbine cycle in order to reduce the required input data and computational time. In this method he introduced a single variable as a criterion of thermodynamic index of performance feed water heating system that has since been widely used for simple system.

Energy is one of the major inputs for the economic development of any country. In case of developing countries, the energy sectors assume a critical importance in view of the ever increasing energy needs requiring huge investment to meet them.

The industrial revolution is a result of the discovery of how to exploit energy and how to convert into work. For this reason, the return on our investment of heat transfer is compared with the output work transfer and attempts are made to maximize this return. Most of our daily activities energy transfer and energy change.

Energy can be classified into several types based on the following criteria:

(1) Primary and Secondary energy

(2) Commercial and Non-commercial energy

(3) Renewable and Non-Renewable energy

1.3 EXERGY

Exergy is a measure of the maximum capacity of a system to perform useful work as it proceeds to a specified final state in equilibrium with its surroundings. Exergy analysis is done on the basis of second law of thermodynamics.In contrast, exergy analysis will characterize the work potential of a system. Exergy is the maximum work that can be obtained from the system, when its state is brought to the reference or dead state (standard atmospheric conditions).

The main objective of the implementation of an exergy-based approach is to find appropriate trade-off between fuel use and investment cost or environmental impact, in order to improve a process.

Exergy analysis of the systems, which analyses the processes and functioning of systems, is based on the second law of thermodynamics. In this analysis, the efficiency of the second law which states the exact functionality of a system and depicts the irreversible factors which result in exergy loss and efficiency decrease is mentioned. Therefore, solutions to reduce exergy loss will be identified for optimization of engineering installations.

The great advantage of exergy calculations over energy calculations is that it describes exactly where the real losses in processes appear. Furthermore the exergy content stream is a real evaluation of energy it indicates the fraction of energy that really can be used.

1.4 IMPORTANT OF EXERGY ANALYSIS

As energy analysis is based on the first law of thermodynamics, it has some inherent limitations like not accounting for properties of the system environment, or degradation of the energy quality through dissipative processes. An energy analysis

Table 1.1: Comparison of Exergy and Energy

Number	Energy	Exergy
1	It is subjected to the law of conservation	It is destroyed in every real process
2	It is function of the states of the systems under consideration	It is the function of state of the system and of surroundings.
3	It may be calculated on the basis of any assumed reference state.	In this case reference state is taken as environment.
4	It increases with increase in temperature.	For isobaric process, it attains its minimum value at t0 ; at lower temperature ; it increase as the temperature drops.
5	It does not depends on pressure for ideal gases.	It depends on pressure.

does not characterize the irreversibility of processes within the system. The energy balance provides a quantitative interpretation of the thermodynamic analysis, while the exergetic balance is associated to qualitative information, describing the system in its critical points by the irreversibility (losses) occurred in the process.

Exergy destruction is the measure of irreversibility that is the source of performance loss. Therefore, exergy destruction helps to identify the location, the magnitude and the source of thermodynamic inefficiencies in a thermal system.

1.5 OUTLINE OF THESIS

Basic introduction about exergy analysis project work and scope of this work is carried out in **chapter 1.** It includes basic information about energy and exergy. It will give idea about how to use exergy in power plant to improve its performance. It also includes why we should use exergy method instead of energy method.

Chapter 2 deals with literature review of researches that carried out in the field of Thermal power plant. In this chapter the objectives and results of different works on energy and exergy analysis of power plant has been explained.

Chapter 3 deals with theoretical consideration of energy and exergy analysis. It is also giving comparison between energy and exergy.

Chapter 4 deals with plant data of different components and its exergy calculation, lost work and efficiencies. In that different related suggestion has been given by plotting graphs.

Chapter 5 shows the result and discussion. In which suggestion are given to improve performance by looking calculation and plots.

Chapter 6 shows the conclusions and future work.

Chapter 2

LITERATURE REVIEW

The present chapter reviews of the work carried out by various investigators on energy analysis, exergy analysis the work reviews details of methodology, their relative merits and applications to various industries viz steam and gas turbine plants. More emphasis is given on the power generation industries to increase the efficiency and augmentation of power, as it is the main aim of the present study.

2.1 ENERGY ANALYSIS

One of the earliest procedures in the evaluation of power cycle using energy analysis was due to J. K. Salibury[1],[2]. Significant feature of this method, generally known as heat deviation method, where to use the analytic description of the turbine cycle in order to reduce the required input data and computational time. In this method he introduced a single variable as a criterion of thermodynamic index of performance feed water heating system that has since been widely used for simple system.

2.2 EXERGY ANALYSIS

Hotsopoulos and Keenan [3] provide derivation for the batch or no-flow availability (A) and the flow availability (B) by

$$A = u - u_0 + P_0(v - v_0) - T_0(s - s_0) \tag{2.1}$$

end

$$B = (h - T_0 s) - (h_0 - T_0 s_0) \tag{2.2}$$

Gaggroli and Petit [4] gave an intuitive and elegant explanation of availability. Availability was described as commodity that represents the potential to cause the change. Kestin [5] presented a series of observation regarding availability concept to industrial process efficiency. The observations were as follows:

1. All industrial process occurs in the terrestrial environment that is an inexhaustible source (or sink) of energy, work and matter.

2. Natural resource is a substance which is not in equilibrium with atmosphere and which can produce work by changing its thermodynamic state.

3. The thermodynamic state of a resource can be reduced to a state in equilibrium with the atmosphere. No further processes are possible.

4. The work made available by changing the state of natural resources can be used to transform the state of substances present passively in equilibrium with the environment of another system.

A better approach to exergy analysis has been developed by Ahern [6], Kotas [7] and Szargut [8]. The specific exergy of a stream of matter (in the absence of nuclear effects, magnesium, electricity and surface tension) is due to the contribution of kinetic, potential, physical and chemical exergy.

2.3 LOST WORK APPROACH

For an isolated system undergoing an irreversible process there is always an increase in Entropy .this increase in entropy has been defined an entropy creation [△Sc] by haywood entropy creation sc during finite change of state is defined as

$\triangle s_c = \triangle s$ - [$\sum$Qi/Ti + $\sum$ (ms)j]B

Never and seader preferred the term s irreversible for the entory creation. The difference in the work output between the reversible and irreversible processes between the specified states is the lost work due to the irreversibility defined by

$$L.W = To \triangle s_c \tag{2.3}$$

The incorporation of the created entropy term converts the second law inequality into an equation for entropy balance.

G. P. Verkhivker and B.V. Kosoy [9] wrote on the exergy basis of power plant that a reduction in exergy destruction is achieved by increasing the value of the thermodynamic parameter of the working fluid supplied to the turbine and by reducing the temperature differences of the net heaters.

Mofid Gorji-Bandpy [10] Noshirvani University of Technology, Iran worked on the topic which is Exergy, The potential work. In this author has conclude that, for particular plant, the exergy analysis shows that the re-heater part of boiler has the lowest exergy efficiency and the evaporator has highest exergy losses. This report shows that natural gas is better than diesel fuel in producing vapour in the boiler.

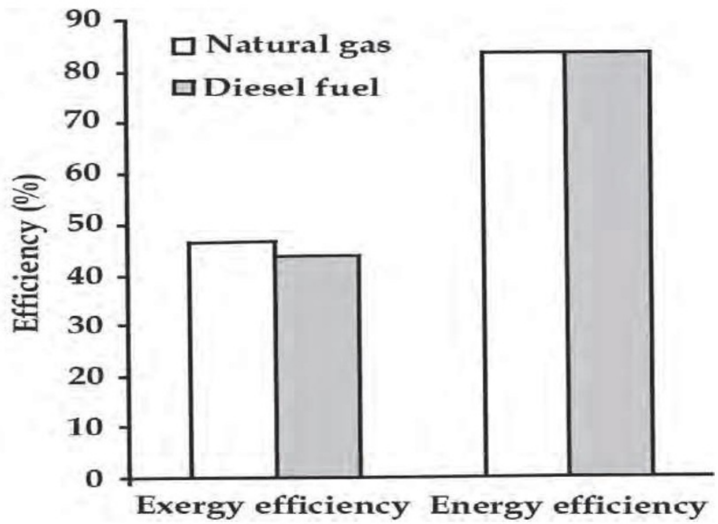

Figure 2.1: comparison of Exergy and Energy efficiency

G. BoroumandJazi et. al [11] published a paper on "A review on exergy analysis of industrial sector" and Compared the energy efficiency analysis and exergetic efficiency of a system. He explained that the exergy analysis provides more realistic picture considering the irreversibility and potential optimization of the process.

S.C Kaushika et. al [12] reported in the paper "Energy and exergy analyses of thermal power plants" that exergy analysis helps to understand the performance of coal fired, gas fired combined cycle thermal power plants. It helps to identify design possible efficiency improvements. It gives logical solution improving the power production opportunities in thermal power plants.

By the exergy analysis it can be concluded that the major energy loss occur in boiler in coal based thermal power plant and for gas fired combined cycle thermal

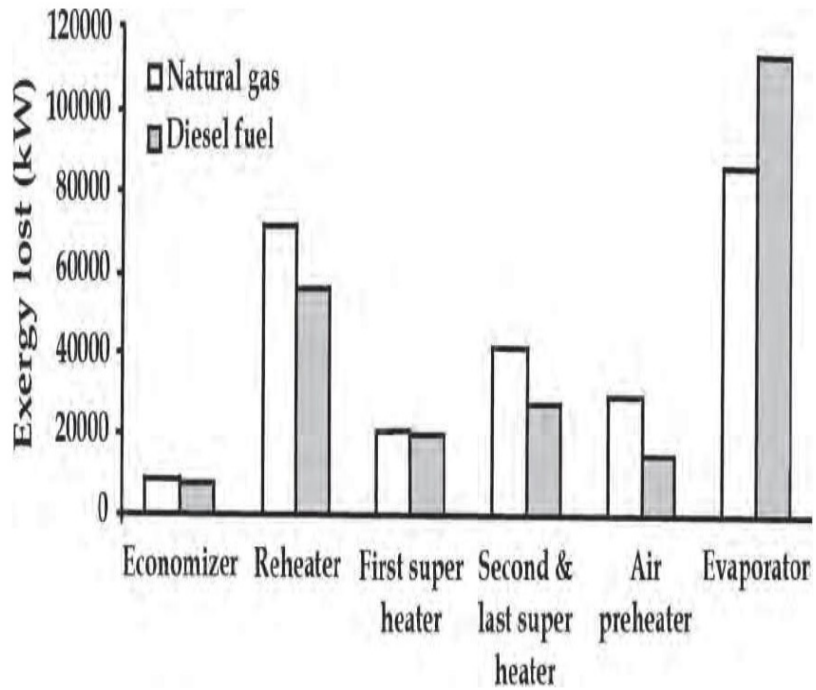

Figure 2.2: Exergy lost for different components of boiler

power plant it occur in combustion chamber.

P. Regulagadda et. al [13] published a paper "Exergy analysis of a thermal power plant with measured boiler and turbine losses". Second law analysis of a thermal power plant has been performed in this paper. It contains the parametric study that considers the effects of various parameters like operating temperature and pressure on the system performance. The power plant's energy efficiency is determined to be 30.12 % for the gross generator output.

The plant exergy efficiency for the system is 25.38 % for the gross generator output. The maximum exergy destruction is found to occur in the boiler. As a result, to improve the performance of the power plant, it should be directed at improving the boiler performance, since this will lead to the largest improvement to the plant's efficiency.

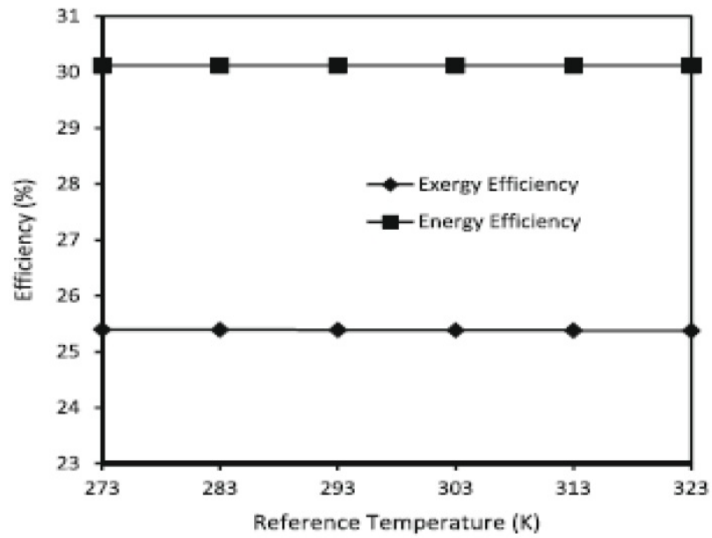

Figure 2.3: Efficiency with respect to temperature

RUBENS ALVES DIA Unesp (Guaratinguet, Brasil) et al [14] reported in the paper which is Energetic and Exergetic Analysis in a Firewood Boiler that Based on the analysis of Thermodynamics first and second laws. Based on the Energy Conservation studies followed three action may be prescribed:
(1) The first is destined to the efficiency estimation of components and/or the whole system, and consequently deciding whether or not it is necessary some intervention;
(2) As it is given in second action these results more elements are available for decisions about implementing or expanding an industrial plant;
(3) Last, this analysis can be viewed for the manufacturers as a tool for the performance study of equipment, through the location of critical points, mainly by the use of exergetic analysis.

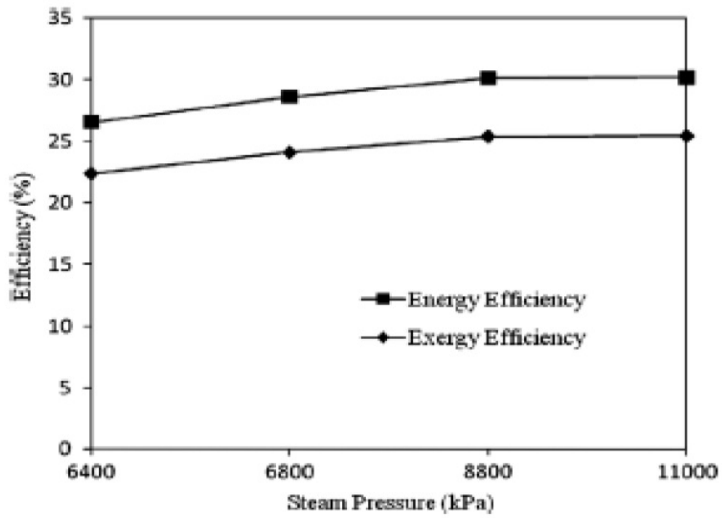

Figure 2.4: Efficiency with respect to pressure

Li Wang and Nianping Li [15] wrote on paper named ”Exergy transfer and parametric study of counter flow wet cooling towers” that the thermal efficiency and water-to-air ratio have complex effects on exergy performance of the CWCT.Performance is very close to 1.0 especially at the conditions of lower water-to-air ratio and higher thermal efficiency.

Denbig [16] applied lost work approach to a process for oxidation of ammonia to 60 % nitric acid. He found that the thermodynamics efficiency of a typical ammonia oxidation process to be 6 %. He also computed the inevitable loss by prescribing a degree of irreversibility and found the practical efficiency of the process that is 32 %.Denbigs analysis showed the possibility of using lost work concept to determine the exergetic efficiency of chemical process.

The exergy analysis of a sulphuric acid plant has been presented by Ravindrnath and Thiyagarajan. The calculation have been performed for a 100 Ton/day double contact double absorption sulphuric acid plant.

Yasni and Carrington [17] carried out off design exergy audit of 250 MW power station in Huntley, N.Z.Tests were carried out, in both design and non-standard modes of operation. In the first case unit operating first with and second without top heater at nominal load and in the second case unit operating first with throttle control mode and second with sliding pressure control mode at nominal load of 150 MW. All the data were collected during heat rate acceptance test of the unit.

Removal of one heater in first case resulted in an increase in steam cycle heat rate of 76kJ/KWh and increase in exergetic losses in boiler, condenser and feed water heaters from 54.6 to 57.07 % whereas turbine exergetic losses reduced from 4.7 to 4.26 %.As the governor valves were partly closed due to reduction of steam flow, which cause increase in throttle losses, by .13 % .Exergetic efficiency of L.P turbine was found to increase from 80.12 to 83.04 %.Author finally conclude that first law analysis resulted only in increase in heat rate by 76kJ/KWh while second law analysis reflect more faithfully the machinery performance, namely increase in L.P turbine efficiency.

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2.4 SCOPE OF THE PRESENT WORK

The present work is concerned with analysis of thermal power plant at ESSAR LTD, HAZIRA. The exergy analysis is carried out, using data of the plant operation. The dissertation work examines the power augmentation of power plant and both energy and exergy distribution and losses in various component of the plant with various aspects of the second law analysis. Based on energy and exergy analysis, Sankey diagram for pictorial representation of energy and exergy distribution in various component are discussed. And also thermal efficiency, boiler efficiency and overall efficiency will be compared in this work.

In this dissertation work exergy for major components of power plant like boiler, turbine, condenser and cooling tower will be calculated. After that looking to the lost work different suggestion will be given to improve its performance.

So, these are different energies which are very useful to any natural process or to do any work. But exergy is the term which also plays important role as energy.

Chapter 3

THEORETICAL CONSIDERATION

The objective of the chapter is to introduce in detail the energy and exergy analysis and procedure for the computing first law and second law (exergetic) efficiency and their merits and demerits. The principle of conservation of mass is used to find out the mass flow rate for a given capacity and sizes of various components. The energy analysis enables one to correlate the performance with working condition of the system. This enables us to find out the degree of perfection of the system and enable us to find the extent to which performance can review the proposals for improvement without resorting to the costly and time consuming trial and error method.

It is known fact that no process consumes even a single unit of energy and it is the quality of energy that is consumed in the processes. The quality deteriorates in an irreversible process. Thus the second law of thermodynamics, the law that governs the quality of energy is used for the analysis and assessment of the thermal system

3.1 METHODOLOGY OF FIRST LAW ANALYSIS

The first law of thermodynamics states that when a system executes a cyclic process, the net work is proportional to the net heat. Mathematically

$\int dW = \int dQ$

Heat and work are different forms of same entity called energy which is conserved. Energy which enters the system as heat may leave the system in form of work, or energy which enters the system as work may leave the system in form of heat.

For non-cyclic process, the increase of energy of system, during the change of state is numerically equal.

$Q - W = \triangle E$

Thus in general first law gives the following distinct assertions.

- A system can interact with its surroundings in only two ways namely heat and work.
- There is property called energy whose change gives net effect of these interactions.

In thermodynamics, a heat engine is defined as a continuously operating system at the boundary of which there is heat and work interaction. It is important to note that for conservation of energy, it is necessary to pursue two objectives namely: reducing the demand of energy and to supply this demand at the maximum possible efficiency. The second objective is within the field of engineering community.

The concept of first law efficiency for heat engines or in general for thermodynamics cycle representing the fractional part of the heat supplied to a cycle, which is converted into work.

$$Efficiency = W/Q_h \tag{3.1}$$

Therefore the first law efficiency is the ratio of quantitative value of desired output to the quantitative value of input used to produce the result. The efficiency of different energy system involving different types of energy input and output cannot be compared directly. Identification of particular energy quantities as output and input gives rise to different definitions for efficiency. Such definitions some times (As in case of electrically driven pumps and refrigerators) give rise to efficiency greater than one. This is in turn appearing anomalous.

The first law of thermodynamics has several short coming as given below.

- Its maximum value may be greater than one, equal to or less than unity. (Depending upon the device and on the temperature.)
- It cannot be readily generalized to complex system in which the output is combinations of heat and work. (As in total energy system.). This is because in the eyes of first law work and heat are equivalent quantitatively and qualitatively.
- It completely ignores the second law implications, which play the central role governing energy resources utilization and conservations.

3.2 METHODOLOGY OF SECOND LAW ANALYSIS

Here the method of exergy analysis used is presented. The concept of exergy is extensively discussed. Exergy is defined as the maximum work potential of a material or of a form of energy in relation with its environment. This work potential can be obtained by reversible process. For practical reasons a reference environment has been defined for the environment. The reference atmosphere is conserved to be so large, that their parameters are not affected by interactions with the system under considerations.

To perform an exergy analysis first closed material and energy balances have to be made. Off course, a closed mass balance includes a closed automatic balance in case of non-nuclear reactions. Exergy transfer with work heat interaction and exergy associated with mass flow. Other components of exergy transfer are neglected, like potential and kinetic exergy or nuclear effect.

3.3 CONCEPT OF EXERGY AND AVAILABILITY

The concept of availability and exergy are concerned with a special type of system, the combined system made up of the control mass and its environment, and the maximum work which can be performed by it. When the control mass passes from its initial state to one in which it is in thermal and mechanical equilibrium with the environment, then there can be no spontaneous change within the control mass or within the environment is called the restricted dead state.

The concept of the control mass is not permitted to mix with the environment, or enter into chemical reaction with the environment component. It is this dead state which is of relevance in calculation of availability. A more general dead state would be one in which the system and the environment are additionally in chemical equilibrium, so that additional work will be released as a result of the difference in composition between the content of control mass and environment. Its determination requires a detail description of the state of the environment. It is this dead state which is of relevance in calculation of exergy.

The magnitude of availability depends on two states, the state of the control mass and that of the environment. The magnitude is independent of the particular series of ideal process followed during the course of establishment of equilibrium. The part of this maximum work may be expanded in pushing back the atmosphere and hence will not be delivered beyond the boundaries of the environment. Such work is to be excluded in the calculation of maximum useful work.

3.4 AVAILABLE ENERGY REFERRED TO A CYCLE

The maximum output obtain from a certain heat input in a cyclic heat engine is called available energy. The minimum energy that has to be rejected to sink by second law is called unavailable energy (U.E) or unavailable part of energy supplied.

$$Q_1 = A.E. + U.E \tag{3.2}$$

$$W_{MAX} = A.E. = Q1 - U.E \tag{3.3}$$

For a given source and sink temperature T1 and T2

η= 1 -(T2/ T1)

For a given T1rev will increase with the decrease of T2, the lowest practicable temperature of heat rejection is the temperature of surrounding.

$$\eta_{max} = 1 - (T_0/T_1) \tag{3.4}$$

$$W_{max} = (1 - T_0/T_1)Q \tag{3.5}$$

Let us consider a finite process x-y in which the heat is supplied reversibly to a heat engine. Take elementary cycle, if dQ1 is heat received by engine reversibly at T1 then,

$$dW_{max} = (T_1 - T_0)/T_1 dQ_1 \tag{3.6}$$

$$= dQ_1 - (T_0 - T_1)dQ_1 \tag{3.7}$$

= A.E.

For heat engine receiving heat for the whole process x-y and rejecting heat at T_0
dWmax = dQ1 - (T0/T1) dQ
A.E = Wmax = Qxy -To (s$_y - s_x$)
$U.E = Qxy - Wmax$
$U.E = T0 - (s_y - s_x)$

3.5 QUALITY OF ENERGY

Let us assume that hot gas is flowing through pipelines. Due to heat loss to the surrounding, the temperature of gas decrease continuously from inlet at state a to the exit at state b although the process is irreversible, let us assume a reversible isobaric path between in the inlet and exit state of the gas, for an infinitesimal process at constant pressure.

ds=mCpdT/T

dT/ds=T/mCp

Q=mCp(T1-T1)

W1=Q-T0$\triangle$s1

Heat Loss(Q) = mCp(T2-T2)= T2$\triangle$s2

W1=Q-T0$\triangle$s2

Since T1$\succ$T2

$\triangle$s1 $\prec$ $\triangle$s2

Therefore,

W1$\succ$W2

The loss of available energy is more; when heat loss at a higher temperature T_1 then when the same heat loss at a lower temperature T_2. Therefore, a heat loss 1 kg at, say, 1000^0C is more harmful than the same heat loss of 1 kg 100C. Adequate insulation must be provided for high temperature fluid (T$\succ$T0), since the loss of available energy from such fluids would be low. (Similarly insulation must be provided adequate for very low temperature fluids (T$\prec$T0) to prevent heat gain from surrounding and preserve available energy.)

The available energy or exergy of a fluid at a higher temperature T_1 is more than that at a lower temperature T_2, and decrease as the temperature decreases.

An awareness of this energy quality as of energy quantity is essential for the efficient use of our energy resources conservation. The concept of available energy or exergy provides a useful measure of this energy quality.

3.6 LAW OF DEGENERATION OF ENERGY

The available energy of a system decreases as its temperature or pressure decreases and approaches that of the surroundings. When heat is transferred from a system, its temperature decreases and hence the quality of its energy deteriorates. The degradation is more for energy loss at higher temperature than that at a lower temperature. Quantity wise the energy loss may be the same, but quality wise the losses are different. While the first law states that energy always degrades quality wise. When a gas is throttled adiabatic from a high to lower pressure, the enthalpy (or energy per unit mass) remains the same, but there is degradation of energy or available work. If the first law is law of conservation energy, the second law is called the law of degradation of energy. Energy is always conserved but its quality is always degraded.

3.7 IRREVERSIBILITY

Irreversibility is the destruction of availability in any real process. Unlike energy, availability is not conserved it is destroyed due to irreversibility. The effect of irreversibility, embodied in the production of entropy, is to decrease the work below the maximum work. The destruction of availability is proportion to creation of entropy due to irreversibility. The quantitative expression of the above statement is termed as Guoy-Stodola theorem.

When W_R and W_I are the work corresponding to the reversible and irreversible process between the same end state and $\triangle$S is total entropy generated in the irreversible process. I is amount of work loss as a result of irreversibility.

The introduction of exergy balance was an important step in the development of the second law analysis. Exergy doesn't follow the principle of conservation. On the contrary decrease of exergy takes place. Therefore exergy balance is to be carried out by taking into consideration the losses of work. The exergy received by a system during a process equal to the sum of increase of exergy of system, exergy leaving the system and loss of exergy during this process. Exergy leads to the concepts or exergetic efficiency, which takes into consideration the quality of energy.

3.8 EXERGETIC EFFICIENCY

For a control volume at steady state the exergy equation can be written as follows,
Exergy = Exergy out in product + Exergy loss + Exergy destruction

The exergetic efficiency is a measure of performance in terms of optimal performance permitted by both first and second laws of thermodynamics and is devoid of the drawbacks inherent in the definition of first law efficiency. For a device whose output is either work or heat transfer, it is detained as a ratio of energy transfer achieved by device or system to the maximum possible heat or work usefully transferable by any device or system using the same energy input as the given system. While numerator is same for both first and second law efficiencies, the denominator in latter case brings both laws of thermodynamics directly into the definition of efficiency. First law focuses attention on reading losses, to improve efficiency. The second law efficiency point out that both losses and internal irreversibility need to be improve performance.

From exergy balance, exergetic efficiency EX, is defined as,

$$\eta_{EX} = \frac{E_{out}}{E_{in}} \tag{3.8}$$

$$\eta_{EX} = 1 - [\frac{(Loss + Destruction)}{Input}] \tag{3.9}$$

Percentage loss of exergy in the component is defined as follows,

$$\eta_{EX} = [\frac{(Loss + Destruction)}{Input}] * 100 \tag{3.10}$$

Thus one can find out the component in which the losses are considerable, so that one can be suggest the ways of reducing the losses and thus increase the exergetic efficiency.

3.9 EXERGY VERSUS ENERGY

The great advantage of exergy calculations over energy calculations is that exergy calculations gives exactly real losses in processes appear. Furthermore the exergy content stream is a real valuation of energy it indicates the fraction of energy that really can be used.

Exergy gives a measure for the quality of energy. This applies on the process component level, the process level and the life cycle level.

3.9.1 EXERGY ON THE PROCESS COMPONENT LEVEL

HEAT

Energy clearly indicates on the process component level that what losses appear. Imagine a heat exchanger in which a process stream is heated from 25^0C to 100^0C by a process stream of 200^0C, which is cooled down to 120^0C. In effect heat is transported from 200^0C to 100^0C. Stream has much lower exergy content than it has at 200^0C. Hence a considerable amount of exergy is lost. Energy might not be lost, but due to the exergy loss, elsewhere in the process an extra amount of fuel might be needed in order to provide heat at, let's say, 160^0C.

PRESSURE

In a valve, no energy is lost, but exergy is. Due to pressure relieved in a valve in a recycle circuit for example, a compressor is needed to restore the pressure. So exergy losses in the valve have a direct influence on the power requirement of the compressor.

CHEMICAL EXERGY

Chemical reactions as such often result in extensive exergy destruction. There will not be any energy losses occur in the reaction. The exergy calculations show that the production of entropy can cause few tens of percent of potential shaft work to be destructed in the reaction. It could reduce exergy losses dramatically in electrochemical membrane reactor (a fuel cell) as given in this approach.

3.9.2 EXERGY ON THE PROCESS LEVEL

On the process level, exergy gives the only way to draw consistent energy balances. In the case of any stream power plant, steam is produced in boiler. The exergy value of steam is much lower that its energy value. So simply drawing an energy balance over the process would lead to wrong perceptions of the process performance.

3.9.3 EXERGY ON THE LIFE CYCLE LEVEL

On the life cycle level, exergy can very well take into account the hidden energy in substances. In the production of steel, much energy is needed. Part of the energy however is stored in the steel as chemical energy or exergy. In an energy balance this term would not occur and the amount of energy losses appointed to this process would be too high. About 1.1 kg of oil will be required in the production of 1 kg polyethylene. It would be completely false to appoint 1.1 kg of oil as the energy use of the process. The use of exergy calculations will yield a consistent way of taking into account the exergy stored in the polymer during its whole life cycle.

Since exergy calculations gives more easier way of accounting losses on the process level, the accumulation of these processes in the life cycle calculations will also calculated.

3.10 COMPARISON OF FIRST AND SECOND LAW AND ENERGY AND EXERGY

Table 1 and Table 2 provide the comparisons between first and second law and energy and exergy, respectively.

Table 3.1: Comparison of 1^{st} and 2^{nd} law

Number	**First Law**	**Second Law**
1	In the eyes of first law, heat and work are of equal	Work is considered to be superior to heat
2	First law results in the definition of the extensive property energy	Second law results in the definition of the extensive property entropy
3	First law states that energy of isolated system can be neither created nor destroyed	Second law states that the entropy of an isolated system also can not be destroyed, but it can be created
4	Clausius: the energy of the universe is constant	Clausius: the entropy of the universe increases towards maximum
5	In every real process energy is conserved	In every real process, in addition, energy is degraded
6	No directional implication concerning possibility of real processes	Is the only natural law relating to the possible direction of real process
7	necessary but not a sufficient condition for a real process	In conjunction with the first law constitutes the necessary and sufficient condition for a real process
8	The first law efficiency is the ratio of the energy transfer of the desired type achieved by device or system to the energy input to the device or system	It is the ratio of the energy transfer achieved by the device or system to the maximum possible heat or work transferable by any system using the same energy input as that given to the system
9	The maximum value of efficiency depends on the type of system considered and may be greater than, less than or equal to 1	The maximum value of efficiency is always less than 1
10	Without the means to discriminate between the qualities of different forms of energy, it is insufficient to provide guidelines for achieving energy resources conservation	For any task requiring heat or work, maximizing the second law efficiency is equivalent to minimizing energy resource consumption

Table 3.2: Comparison of Exergy and Energy

Number	**Energy**	**Exergy**
1	It is subjected to the law of conservation	It is destroyed in every real process
2	It is function of the states of the systems under consideration	It is the function of state of the system and of surroundings.
3	It may be calculated on the basis of any assumed reference state.	In exergy reference state is imposed by the environment.
4	It increases with increase in temperature.	For iso-baric process, it gain its minimum value at t0 ; at lower temperature ; it increase as there is drop in temperature.
5	It does not depends on pressure for ideal gases.	It depends on pressure.

Here it is explained the theoretical aspects of Energy and Exergy. Based on this consideration exergy calculation has been made as shown in chapter 4.

Chapter 4

METHODOLOGY OF ENERGY AND EXERGY ANALYSIS

The Energy analysis of power plant is carried out in order to calculate energy losses and energy distribution in the system. For this law of conservation of mass and energy are applied to each control volume of system.

4.1 PHYSICAL AND CHEMICAL COMPONENT OF EXERGY

Because of disordered, entropy dependent nature of these forms of energy, the corresponding exergy component can only be determined by considering a composite two part systems, the steams under consideration and the environment.

4.1.1 PHYSICAL EXERGY

Physical exergy is equal to the maximum amount of work that can be abstract when the streams of is brought into the environmental state from its initial state to defined by streams of Po and To by physical process involving only thermal interaction with the environment.

Exp = Ex△T + Ex△P

Physical exergy = thermal component of physical exergy + pressure components of Physical energy

$$E_{xph} = C_{Ph}(T - T_o) - T_o[C_P ln(T/T_o) - R ln(P/P_o)] \tag{4.1}$$

4.1.2 CHEMICAL EXERGY

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 heat transfer and exchange of substance only with the environment.

$$E_{xo} = X_i E_{oi} + RT_o X_i nX \tag{4.2}$$

4.2 IRREVERSIBILITY

Irreversibility is the destruction of availability in any real processes. Unlike energy, availability is not conserved; it is destroyed due to irreversibility. The effect of irreversibility, embodied in the production of entropy, is to decrease the work below the maximum work.

The quantitative expression of the above statements is termed the Guoy Stodola theorem;

$$I = W_{loss} = W_R - W_I \tag{4.3}$$

$$I = T_o s \tag{4.4}$$

Where W_R and W_I are the work corresponding to the reversible and irreversible process between the same end state and △s is total entropy generated in the irreversible process. It amount of work loss as a result of irreversibility.

The introduction of exergy balance was an important step in the development of second law analysis. Exergy doesn't follow the principle of conservation.

Therefore exergy balance is carried out by taking into consideration of losses of work exergy balance leads to exergetic efficiency, which takes into consideration the quality of energy.

The exergy analysis of thermal power plant is carried out in order to find out the lost work i.e. the difference in exergy supplied and exergy output is the lost work of the system or components.

Here the plant data for boiler and turbine is listed bellows and calculation for exergy is given respectively

Table 4.1: **Essar power plant data for October 2013**

No	**Description**	**Temp (^{0}C)**	**Pressure (bar)**	**Enthalpy (kJ/kg)**	**Entropy (kJ/kg*K)**
1	Main stream level	425	35.62		
2	Process steam flow				
3	Feed water				
4	Feed water before Economizer	86.84	54.76		
5	BF gas line		0.07430		
6	Natural gas line		0.24450		
7	Furnace	750	1.30		
8	Atmosphere air	27	1.013	111.8	0.391
9	Primary super heater	264	36.7	2822	6.20
10	Secondary super heater	289	36.7	2970	6.430
11	Primary air preheater	37	1.013	2570	8.30
12	Secondary air preheater	89	1.013	2658	7.492
13	Primary Economizer	100	1.013	419	1.307
14	Secondary Economizer	160	1.013	2770	7.630
15	Super-heater- 1 O/T	369	36.7	3115	6.68
16	Super-heater- 2 O/T	430	36.7	3290	6.88
17	Air-preheater- 1 O/T	89	1.013	2658	7.492
18	Air-preheater- 2 O/T	183	1.013	2778.85	6.558
19	Economizer- 1 O/T	145	1.013	612	1.795
20	Economizer- 2 O/T	250	1.013	1085	2.78
21	Dearator		0.67		
22	Turbine inlet	433	33.90	3260	6.90
23	Turbine outlet	51	0.12961	2714.4	7.067
24	Cold blast	182	2.3935		
25	Turbine speed		4150 RPM		

4.3 BOILER EFFICIENCY

4.3.1 DIRECT METHOD

Direct method is also known as ”input-output” method,Where the energy gain of the working fluid (water and steam) is compared with the energy content of the boiler fuel. Due to the fact that it needs only the useful output (steam) and the heat input (fuel) for evaluating the efficiency. This efficiency can be calculated using formula.

$$Efficiency\eta = \frac{(Heatoutput)}{(Heatinput)} * 100 \tag{4.5}$$

$$Efficiency\eta = \frac{(Q * (Hg - Hf))}{(q * G.C.V)} * 100 \tag{4.6}$$

Q= Quantity of steam generated = 65T/H

q=Quantity of fuel used per hour =68T/H

Hg= Enthalpy of saturated steam = 2770 kJ/kg

Hf= Enthalpy of feed water = 419.1 kJ/kg

G.C.V = 2548 kJ/kgK

η =(65*(2770-419.1))/(68*2548)*100

=88.19%

4.3.2 INDIRECT METHOD

Calculation for G.C.V

For 1kg of gas mass of composition

= (0.15*44) + (0.015*2) + (0.24*28) + (0.59*28) + (0.005*16)

Table 4.2: Gas composition in Blast Furnace gas

No	**Gas Composition in BF gas**	%	**Unit**	**Mole(Kg/k*mole)**
1	CO_2	15%		44
2	H_2	1.5%		2
3	CO	24%		28
4	N_2	59%		28
5	CH_4	0.5%		16
6	O_2	0%		32
7	S_2	0%		
8	G.C.V OF FUEL	2548	KJ/kg*K	

= 29.95 Kg/k*mole

Now, for NTP 1 m3 = 29.95 Kg/k*mole

For 1 kg of gas at STP volume must be 22.4 Nm3

= 29.95/22.4

= 1.33 kg/mole

At STP for 22.4 Nm3 or 1 kg of gas its calorific value is 800 K*Cal/mole

So, 800/1.33 = 601.5037 K*Cal/kg

= 601.5037*4.187

= 2548 kJ/kg*K

Energy Assessment Calculation

Step 1 : Check the given composition is wet basis or dry basis

Step 2 : Given composition is on wet basis

Combustion of Carbon

C + O_2 = CO_2

12 + 32 = 44

0.15 + 32/12*0.15 = 44/12*0.15

Mass of carbon = 0.15 kg

Mass of oxygen = 0.4 kg

Combustion of Hydrogen

$H_2 + 1/2O_2 = H_2$O

2 + 16 = 18

0.015 + 8*0.015 = 9*0.015

Mass of Hydrogen = 0.015 kg

Mass of Oxygen = 0.12 kg

Theoretical O2 Required

$O2)_{TH}$ = $O2)_C$ + $O2)_{H2}$ -$O2)_{FUEL}$

= 0.4 + 0.12 -0

= 0.52

Theoretical N2 Required

23 kg of O_2 = 77 kg of N_2 = 100 kg of Air

0.52 kg of O_2 = 77/23*0.52 = 100/23*0.52

0.52 kg of O_2 = 1.7401 kg of N_2 = 2.26 kg of Air

$N2)_{TH}$ = 1.74 kg/kg of Fuel

Table 4.3: Molecular weight of gases

No	Composition	Mass (kg/kg of fuel)	Molecular mass	Molecular (Wet basis)	Molecular (Dry basis)
1	CO_2	0.55	44	0.0125	0.0125
2	M.C+H_2O	0.135	18	7.5 * 10^{-3}	0
3	SO_2	0	64	0	0
4	$O2)_{EXCESS}$	0.013	32	4.18 * 10^{-4}	4.18 * 10^{-4}
5	$N2)_{FUEL}$ $+N2)_{TH}$	2.330	28	0.083	0.083
6	$AIR)_{TH}$	2.261			
7	$N2)_{EXCESS}$	0.226	28	8.08 * 10^{-3}	8.08 * 10^{-3}
8	$\sum$ DRY	3.11			

Mass of O2) EXCESS = 0.013 kg/kg of fuel

Exess air is taken as 10% from TERI handbook.

Theoretical air required

$Air)_{TH} = N2)_{TH} + O2)_{TH}$

= 1.7401 + 0.52

= 2.26 kg/kg of fue

Actual Air = $Air)_{TH} + O2)_{EXCESS} + N2)_{EXCESS}$

= 2.261 + 0.0134 + 0.2264

= 2.50 kg/kg of fuel

LOSSES

DRY GAS LOSS(STACK LOSS)

Q_{dfg} = (M_{dfg}*C_p*(T_{fg}-T_a))/(G.C.V)*100

M_{dfg} = 3.11 kg/kg of fuel

T_{fg} = Chimney out temperature = 126^0

T_a = Atmosphere temperature = 27^0

= (3.1199*1.005*(126-27))/2548*100

= 12.18 %

LOSSES DUE TO H2 IN FUEL

Q_{H2} = (M_{H2O}*H)/(G.C.V)*100

M_{H2O} = 9 * H

= 0.135 kg/kg of fuel

H = C_{PI} T + H_L + C_{PW} T

= 4.2 (24-27) + 2444.6 + 1.88 (126-24)

= 2623.76kJ/kg

Q_{H2} = (0.0135*2623.76)/2548*100

= 1.390 %

LOSS DUE TO MOISTURE

= (Mmc*H)/(G.C.V)*100

Mmc = 0.02 kg/ kg of fuel

H = 2623.76 kJ/kg

= (0.02*2623.76)/2548*100

= 2.059 %

Some assumed losses are based on plant condition and atmosphere

RADIATION LOSS = 1.0 %

BLOW DOWN LOSS = 0.5%

TOTAL LOSS = 100 (STACK LOSS + LOSSES DUE TO H2 IN FUEL + LOSS DUE TO MOISTURE + RADIATION LOSS + BLOW DOWN LOSS)

= 100 (12.182 + 1.390 + 2.059 + 1 + 0.5)

$\eta = 82.86\%$

4.4 EXERGY ANALYSIS OF COMPONENTS

4.4.1 INTRODUCTION

Exergy analysis is the methodology for the evolution of the performance of devices and process. It involves determining the exergy at different places in energy conversion steps. With the help of this steps efficiencies can be evaluated and which components having the largest losses can be identified. Exergy analysis is now a days very useful aspect to understand the process, to quantify the efficiency of different components of plant and to distinguish quality of energy used.

Now a days exergy analysis is a much stronger emphasis on the system and process. The emphasis is now on a system analysis and thermodynamic optimization, Exergy analysis is not only in the mainstream of engineering but it is related with other branch like physics, economics, biology and management. As a result of this 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. According to the survey in literatures, it is shown that exergy can be divided into four major components. Two important components are physical exergy and chemical exergy out of four.

In this analysis two other components kinetic energy and potential energy are very small compared to others. so, it is assumed to be negligible as the elevation and speed have negligible changes.
Ei = Eiph + Eich

The physical exergy is described when a system interacts with an equilibrium state when the maximum theoretical useful work from system is obtained. The chemical exergy is associated with the departure of the chemical composition of a system from its chemical equilibrium. In combustion process the chemical exergy plays very important role. When it is subjected to first law and second laws of thermodynamics, following exergy balance is obtained,

E_Q = (1- T_0/T_{in}) * Q_{in}
E_W = W

4.5 IRREVERSIBILITY

Irreversibility is the destruction of availability in any real processes. Unlike energy, availability is not conserved; it is destroyed due to irreversibility. The effect of irreversibility, embodied in the production of entropy, is to decrease the work below the maximum work.

The quantitative expression of the above statements is termed the Guoy Stodola theorem;

$$I = W_{loss} = W_R - W_I \tag{4.7}$$

$$I = T_o \triangle s \tag{4.8}$$

Where WR and WI are the work corresponding to the reversible and irreversible process between the same end state and $\triangle$s is total entropy generated in the irreversible process. It amount of work loss as a result of irreversibility.

The introduction of exergy balance was an important step in the development of second law analysis. Exergy doesn't follow the principle of conservation.

Therefore exergy balance is carried out by taking into consideration of losses of work exergy balance leads to exergetic efficiency, which takes into consideration the quality of energy.

The exergy analysis of thermal power plant is carried out to find out the lost work i.e. the difference in exergy supplied and exergy output is the lost work of the system or components.

4.6 EXERGY CALCULATION FOR BOILER COMPONENTS

Here for different parts of the boiler like super heater, Air-pre-heater and Economizer exergy calculation has been made. In this report exergy calculation has been done only for physical exergy. So, one by one physical exergy is calculated. These are follows,

4.6.1 EXERGY CALCULATION FOR SUPER-HEATER

E = m [(h-h_0) - T_0 (s-s_0)]

T_0 = 300K

s_0 = 0.391kJ/kgK

h_0 = 111.8 kJ/kgK

PRIMARY SUPER-HEATER INLET

At 264^0C

P = 36.7 bar

m = 65 T/H = 18.055 kg/s

h_1 = 2822 kJ/kg

s_1 = 6.20 kJ/kgK

E = m [(h-h_0) - T_0 (s-s_0)]

= 18.055 [(2822-111.8)-300(6.20-0.391)]

= 17.46MJ

PRIMARY SUPER-HEATER OUTLET

At 369^0C

P = 36.7 bar

m = 18.055 kg/s

h_2 = 3115 kJ/kg

s_2 = 6.680 kJ/kgK

E = m [(h-h_0) - T_0 (s-s_0)]

= 18.055[(3115-111.8)-300(6.680-0.391)]

= 20.15MJ

SECONDARY SUPER-HEATER INLET

At 289^0C

P = 36.7 bar

m = 18.055 kg/s

h_1 = 2970 kJ/kg

s_1 = 6.430 kJ/kgK

E = m [(h-h_0) - T_0 (s-s_0)]

= 18.055[(2970-111.8)-300(6.430-0.391)]

= 18.89MJ

SECONDARY SUPER-HEATER OUTET

At 430^0C

P = 36.7 bar

m = 18.055 kg/s

h_2 = 3290 kJ/kg

s_2 = 6.880 kJ/kgK

E = m [(h-h_0) - T_0 (s-s_0)]

= 18.055[(3290-111.8)-300(6.880-0.391)]

= 22.23MJ

4.6.2 EXERGY CALCULATION FOR AIR-PRE-HEATER

PRIMARY AIR-PRE-HEATER INLET

At 37^0C

P = 1.013 bar

m = 16.305kg/s

T_0 = 300K

s_0 = 0.391kJ/kgK

h_0 = 111.8 kJ/kgK

h_1 = 2570 kJ/kg

s_1 = 8.3 kJ/kgK

E = m [(h-h_0) - T_0 (s-s_0)]

= 16.305 [(2570-111.8)-300(8.3-0.391)]

= 1394.07 kJ

PRIMARY AIR-PRE-HEATER OUTLET

At 89^0C

P = 1.013 bar

m = 16.305kg/s

h_2 = 2658 kJ/kg

s_2 = 7.492 kJ/kgK

E = m [(h-h_0) - T_0 (s-s_0)]

= 16.305 [(2658-111.8)-300(7.492-0.391)]

= 6781.24 kJ

SECONDARY AIR-PRE-HEATER INLET

At 89^0C

P = 1.013 bar

m = 16.305kg/s

h_1 = 2658 kJ/kg

s_1 = 7.492 kJ/kgK

E = m [(h-h_0) - T_0 (s-s_0)]

= 16.305 [(2658-111.8)-300(7.492-0.391)]

= 6781.24 kJ

SECONDARY AIR-PRE-HEATER OUTLET

At 183^0C

P = 1.013 bar

m = 16.305kg/s

h_2 = 2778.85 kJ/kg

s_2 = 6.558 kJ/kgK

E = m [(h-h_0) - T_0 (s-s_0)]

= 16.305 [(2778.85-111.8)-300(6.558-0.391)]

= 13,320.36kJ

4.6.3 EXERGY CALCULATION FOR ECONOMIZER

PRIMARY ECONOMIZER INLET

At 100^0C

P = 1.013 bar

m = 68 T/H = 18.88kg/s

T_0 = 300K

s_0 = 0.391kJ/kgK

h_0 = 111.8 kJ/kgK

h_1 = 419 kJ/kg

s_1 = 1.307 kJ/kgK

E = m [(h-h_0) - T_0 (s-s_0)]

= 18.88[(419-111.8)-300(1.307-0.391)]

= 611.71kJ

PRIMARY ECONOMIZER OUTLET

At 145^0C

P = 1.013 bar

m = 68 T/H = 18.88kg/s

h_2 = 612 kJ/kg

s_2 = 1.795 kJ/kgK

E = m [(h-h_0) - T_0 (s-s_0)]

= 18.88 [(612-111.8)-300(1.795-0.391)]

= 1491.52kJ

SECONDARY ECONOMIZER INLET

At 160^0C

P = 1.013 bar

m = 68 T/H = 18.88kg/s

h_1 = 676.1 kJ/kg

s_1 = 1.944 kJ/kgK

E = m [(h-h_0) - T_0 (s-$_0$)]

= 18.88[(676.1-111.8)-300(1.944-0.391)]

= 1857.79kJ

SECONDARY ECONOMIZER OUTLET

At 250^{0}C

P = 1.013 bar

m = 68 T/H = 18.88kg/s

h_2 = 1085 kJ/kg

s_2 = 2.78 kJ/kgK

E = m [(h-h_0) - T_0 (s-s_0)]

= 18.88[(1085-111.8)300(2.78-0.391)]

= 4842.72kJ

4.7 CALCULATION OF 2ND LAW EFFICIENCY

Basically 2nd law efficiency is related with entropy term. This will give better idea about the performance of the components than 1st law efficiency. 2nd law efficiency depends on exergy term. According to this law 2nd law efficiency for different components is calculated. Here it is explained by one general example.

$$\eta_{II} = \frac{Exergy\ recovered(Available\ Exergy\ after\ process)}{Exergy\ \ supplied(Available\ Exergy\ at\ beginning)}$$

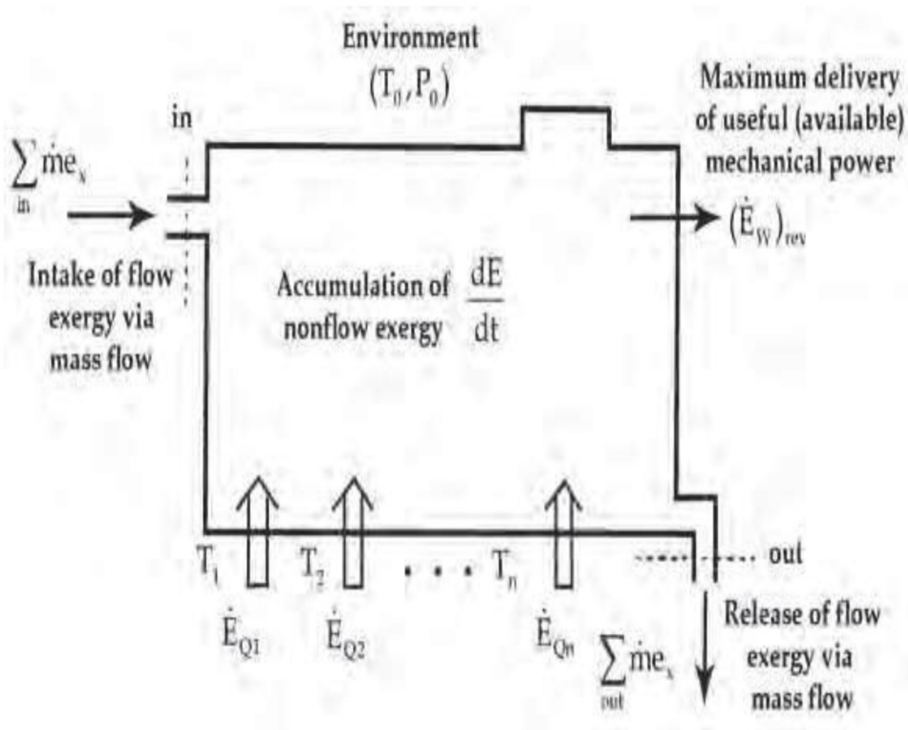

Figure 4.1: General sankey diagram

$$= 1 - \frac{Exergy\ \ destroyed}{Exergy\ \ supplied}$$

To find 2nd law efficiency exergy desruction is to be calculated.

Exergy destruction = m*T_0 *s_{gen}

4.7.1 SUPER-HEATER (PRIMARY)

s_{gen} = (s_1-s_2) = (6.68-6.2)

Exergy destroyed = 18.055*300*(6.68-6.2)

= 2599.92kW

Exergy supplied = 17.468kJ

η_{II} = 1 - (EXERGY DESTROYED)/(EXERGY SUPPLIED)

η_{II} = 1 - 2599.92/17.468

= 85.11 %

SUPER-HEATER (SECONDARY)

s_{gen} = (s_1-s_2) = (6.88-6.43)

Exergy destroyed = 18.055*300*(6.88-6.43)

= 2437.42kW

Exergy supplied = 18.89kJ

η_{II} = 1 - (EXERGY DESTROYED)/(EXERGY SUPPLIED)

η_{II} = 1 - 2437.42/18.894

= 87.09 %

4.7.2 AIR-PREHEATER (PRIMARY)

s_{gen} = (s_1-s_2) = (8.3-7.492)

Exergy destroyed = 16.305*300*(8.3-7.492)

= 242.4kW

Exergy supplied = 1394.077kJ

η_{II} = 1 - (EXERGY DESTROYED)/(EXERGY SUPPLIED)

η_{II} = 1 - 242.4/1394.07

= 82.61 %

AIR-PREHEATER (SECONDARY)

s_{gen} = (s_1-s_2) = (7.492-6.558)

Exergy destroyed = 16.305*300*(7.492-6.558)

= 280.2kW

Exergy supplied = 6781.249kJ

η_{II} = 1 - (EXERGY DESTROYED)/(EXERGY SUPPLIED)

η_{II} = 1 - 280.2/6781.249

= 95.86 %

4.7.3 ECONOMIZER (PRIMARY)

s_{gen} = (s_1-s_2) = (1.795-1.307)

Exergy destroyed = 16.305*300*(1.795-1.307)

= 146.4kW

Exergy supplied = 611.412kJ

η_{II} = 1 - (EXERGY DESTROYED)/(EXERGY SUPPLIED)

η_{II} = 1 - 146.4/611.412

= 76.06 %

ECONOMIZER (SECONDARY)

s_{gen} = (s_1-s_2) = (2.78-1.944)

Exergy destroyed = 16.305*300*(2.78-1.944)

= 250.8kW

Exergy supplied = 1857.79kJ

η_{II} = 1 - (EXERGY DESTROYED)/(EXERGY SUPPLIED)

η_{II} = 1 - 250.8/1857.79

= 86.50 %

4.8 TURBINE

Turbine is one the most essential component of power plant. The main function of turbine is to expand the steam which is coming from the boiler. Turbine is further connected to the generator and produce electricity.

It is very easy to find efficiency of turbine and evaluate the performance of it. It is quite simple too. Thermal efficiency of turbine is related to enthalpy term. But there is no other way to find losses in it. Turbine processes are evaluated with respect to exergy and second law efficiency.

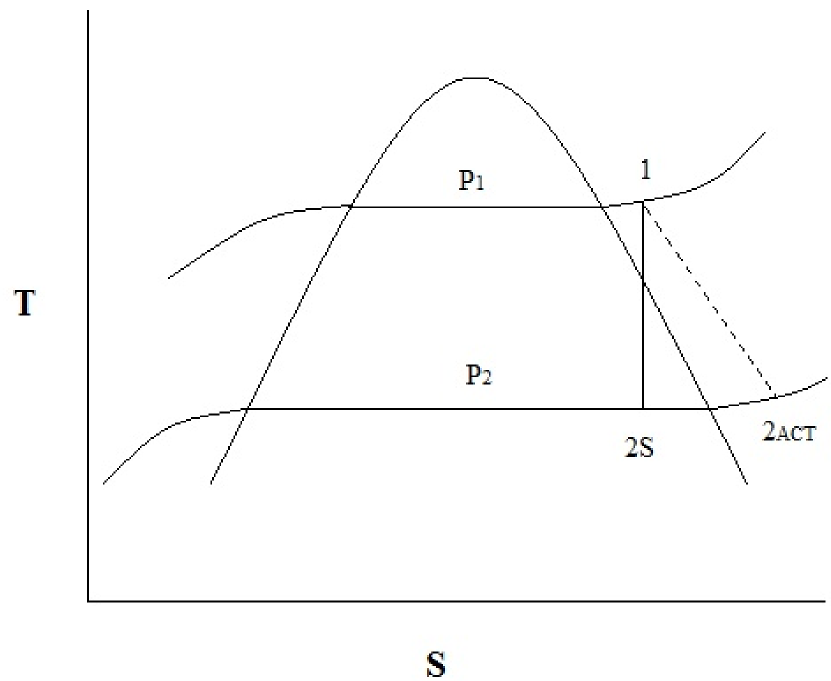

Figure 4.2: T-S diagram for turbine

4.8.1 THERMAL EFFICIENCY

η_T = $((h_1$-$h_{2act}))/((h_1$-$h_{2s}))$

h_1 = Enthalpy at state 1= 3280kJ/kg

h_{2act} = Enthalpy at state 2= 2714kJ/kg

h_{2s} = Isentropic Enthalpy at state 2= 2650kJ/kg

η_T = ((3280-2714))/((3280-2650))

= 0.8984*100

= 89.84 %

4.8.2 EXERGY CALCULATION FOR TURBINE

Inlet steam temperature = 421^0C

Inlet steam pressure = 3.39MPa = 33.90 bar

Outlet steam temperature = 51^0C

Outlet steam pressure = 0.12961 bar

Mass flow rate = 96 T/H = 26.66 kg/s

INLET

h_1 = 3260kJ/kg

s_1 = 6.90kJ/kgK

E_{T1} = m[(h_1-h_0)-T_0(s_1-s_0)]

= 26.66[(3260-111.8)-300(6.90-0.391)]

= 31.87MJ

OUTLET

h_2 = 2714.4 kJ/kg

h_2 = 7.067 kJ/kgK

E_{T2} = m[(h_2-h_0)-T0(s_2-s_0)]

= 26.66[(2714.4-111.8)-300(7.067-0.391)]

= 15.99MJ

4.8.3 2ND LAW EFFICIENCY

Exergy destruction = E_{T1} - E_{T2}

= 31.872-15.990

= 15,88kW

$$\eta_{II} = \frac{\text{outgoing exergy rate}}{\text{incoming exergy rate}}$$

= (15,882*1000)/(31,872*1000)*100

= 49.83 %

Table 4.4: Condenser and Cooling tower data

Sr No	Description	Temp.	Pressure (bar)	Enthalpy (kJ/kg)	Entropy (kJ/kgK)
1	Main stream level	425	35.62		
2	Process steam flow				
3	Feed water				
4	Feed water before economiser	86.84	54.76		
5	BF gas line		0.07430		
6	Natural gas line		0.24450		
7	Furnace	750	1.30		
8	Atmosphere air	27	1.013	111.8	0.391
9	Condenser inlet	109.3	1.40	2689.8	7.25
10	Condenser outlet	49.3	1.40	2591	8.1
11	C.T hot water	36.7	0.87	150.7	0.520
12	C.T cold water	30	19.18	125.7	0.437

4.9 CONDENSER

4.9.1 THERMAL EFFICIENCY

η_C = ((T_0-T_i))/((T_s-T_i))

T_i = Inlet temperature of cooling water= 35^0C

T_0 = Outlet temperature of cooling water= 93.5^0C

T_s = Saturation temp. of steam correspond to absolute pressure in condenser= 109.3^0C

η_C = (Temp. rise of cooling water)/((Temp. of steam-Inlet temp. of cooling water))

η_C = ((93.5-35))/((109.3-35))

= 0.7873*100

= 78.73 %

4.9.2 EXERGY ANLYSIS OF CONDENSER

Inlet steam temperature = 109.3^{0}C

Inlet steam pressure = 0.14MPa = 1.4 bar

Outlet temperature = 49.3^{0}C

Outlet pressure = 1.013 bar

Mass flow rate = 58.308 kg/s

INLET

h_1 = 2689.8kJ/kg

s_1 = 7.25kJ/kgK

E_{C1} = m[(h_1-h_0)-T_0(s_1-s_0)]

= 58.308[(2689.8-111.8)-300(7.25-0.391)]

= 30.33MJ

OUTLET

h_2 = 2591 kJ/kg

h_2 = 8.1 kJ/kgK

E_{C2} = m[(h_2-h_0)-T0(s_2-s_0)]

= 58.308[(2591-111.8)-300(8.1-0.391)]

= 9.70MJ

4.9.3 SECOND LAW EFFICIENCY

Exergy destroyed = 58.308*300*(8.1-7.25)

= 14,868.54kW

η_{II} = 1 - (EXERGY DESTROYED)/(EXERGY SUPPLIED)

η_{II} = 1 - 14,868.54/30,337

= 50.57 %

4.10 COOLING TOWER

Hot water temperature(H.W.T) 36.7^{0}C

Cold water temperature(C.W.T) 30^{0}C

Amb. air W.B.T= 28^{0}C

Amb. air D.B.T = 32.8^{0}C

RANGE = (H.W.T-C.W.T)

= (36.7-30)

= 6.7^{0}C

APPROACH = (C.W.T-W.B.T)

= (30-28)

= 2^{0}C

C.T Effectiveness = $[\frac{(H.W.T-C.W.T)}{(H.W.T-W.B.T)}]$

= $[\frac{(36.7-30)}{(36.7-28)}]$

= 77.01%

4.10.1 EXERGY ANALYSIS OF COOLING TOWER

Inlet water temperature = 36.7^{0}C

Inlet water pressure = 0.87 bar

Inlet mass flow rate = 424.16 kg/s Outlet temperature = 30^{0}C

Outlet pressure = 19.18 bar

Outlet mass flow rate = 241.9 kg/s

INLET

h_1 = 151kJ/kg

s_1 = 0.520kJ/kgK

$E_{C.T1}$ = m[(h_1-h_0)-T_0(s_1-s_0)]

= 424.16[(151-111.8)-300(0.520-0.391)]

= 212.08kJ

OUTLET

h_2 = 125.7 kJ/kg

h_2 = 0.437 kJ/kgK

$E_{C.T2}$ = m[(h_2-h_0)-T0(s_2-s_0)]

= 241.9[(125.7-111.8)-300(0.437-0.391)]

= 24.19kJ

4.10.2 SECOND LAW EFFICIENCY

Exergy destroyed = 424.16*300*(0.520-0.437)

= 10.56kW

η_{II} = 1 - (EXERGY DESTROYED)/(EXERGY SUPPLIED)

η_{II} = 1 - 10.561/212.08

= 96.02 %

Table 4.5: Overall result of calculation

Components	**Exergy Destruction (kW)**	**Exergetic Efficiency** (%)
Superheater-1	2599.92l	85.116
Superheater-2	2437.42	87.09
Air-preheater-1	242.4	82.61
Air-preheater-2	280.2	95.868
Economiser-1	146.4	76.067
Economiser-2	250.8	86.50
Turbine	15,888.2	49.830
Condenser	14,868.54	50.57
Cooling Tower	10.568	96.020

4.10.3 HEAT RATE

Mass flow rate : 99 ton/hr= 27.5 kg/s

Pressure : 30bar

Temperature : 398^0C

Production = 19 MW

1 kJ = 0.238846 Nutrition cal.

Enthalpy = 3220kJ/kg = 769.08 cal/kg

Condenser temp. (INLET)= 52_0C

h = 217 kJ/kg

= 51.829 Cal/kg

Heat Rate : m*(h_T-h_c)/production

= (27.5*(3220-217))/19

$= \frac{82{,}582.5}{19}$

= 4346.44 kJ/sec*MW

4.11 IMPLEMENTATION

Table 4.5 provides the information about exergy destruction efficiency.In that superheater of boiler has maximum efficiency turbine, condenser as well. so, here is step to improve boiler's energy as well as exergetic efficiency.

4.11.1 REDUCE EXCESS AIR

Old mass of actual air = 2.69 kg/kg of fuel

New mass of actual air = 2.5008 kg/kg of fuel

New excess air (%) = $\frac{mass\ of\ actual\ air - mass\ of\ theoritical\ air}{mass\ of\ theoritical\ air}$

$= \frac{(2.5008 - 2.261)}{2.261} * 100$

$= 10.60\%$

$Oldexcessair = 14.55\%$

$Newdrygasloss(stackloss)$

$Qdfg = \frac{MdfgCp(TfgTa)}{G.C.V} * 100$

$OldMdfg = 3.1199 kg/kgoffuel$

$NewMdfg = 2.863 kg/kgoffuel$

$Tfg = Chimneyouttemperature$ =126^0C

Ta = Atmosphere temperature = 27^0C

$= \frac{2.8631.005(12627)}{2548}$ *100

= 11.18 %

TOTAL LOSS = 100 (STACK LOSS + LOSSES DUE TO H2 IN FUEL + LOSS DUE TO MOISTURE + RADIATION LOSS + BLOW DOWN LOSS)

= 100 (11.181 + 1.390 + 2.059 + 1 + 0.5)

New η = 83.87 %

Old η = 82.86 %

4.11.2 REDUCING EXERGY DESTRUCTION IN BOILER

Exergy destruction in both super-heater is very high. So, reduce temperature of superheater by 10^0C to decrease exergy destruction.Temperature reduction will be according to limitation of boiler's parameters.

old E.D = 2437.42kW

Reducing outlet temperature-2 by 10^0C

New quantity of super-heater-2 :

Inlet temperature = 280^0C

$h_1 = 2890 kJ/kg$

$s_1 = 6.450 kJ/kgK$

E_i = m[(h_1-h_0)-T0(s_1-s_0)]

= 18.055[(2890-111.8)-300(6.450-0.391)]

= 17.88MJ

E_o = m[(h_2-h_0)-T0(s_2-s_0)]

= 18.055[(3200-111.8)-300(6.80-0.391)]

= 21.04MJ

NEW OUTLET QUANTITY :

Outlet temperature = 420^0C

h_2=3200kJ/kg

$s_2 = 6.80 kJ/kgK$

Old Exergy destruction = 2437.42kW

New Exergy destruction = m*to*s_{gen}

= 18.055*300*(6.80-6.450)

=1895.77kW

Old efficiency = 87.09%

New efficiency=1- $\frac{E.D}{Ei}$ *100

= 1- $\frac{1895.775}{18883}$ *100

= 88.39%

So, these are the exergy based calculation for different components of power plant. According to calculation several results have been given with the help of charts.And discussion on that plots and results are given in next chapter.

Chapter 5

RESULTS AND DISCUSSION

Results are based on the plant data for year 2013 and so as calculation for exergy and 2nd law efficiencies also.Chapter-4 contains the calculations for different components of power plant and based on that calculation different plots are shown in this chapter.

According to the calculations and plots, suitable suggestion are being given for improving the performance of each components.

5.1 RESULTS

Fig 5.1 is comparison of different components with respect to their thermal efficiency. In that the efficiency for Air-pre-heater is higher than super-heater and economizer.

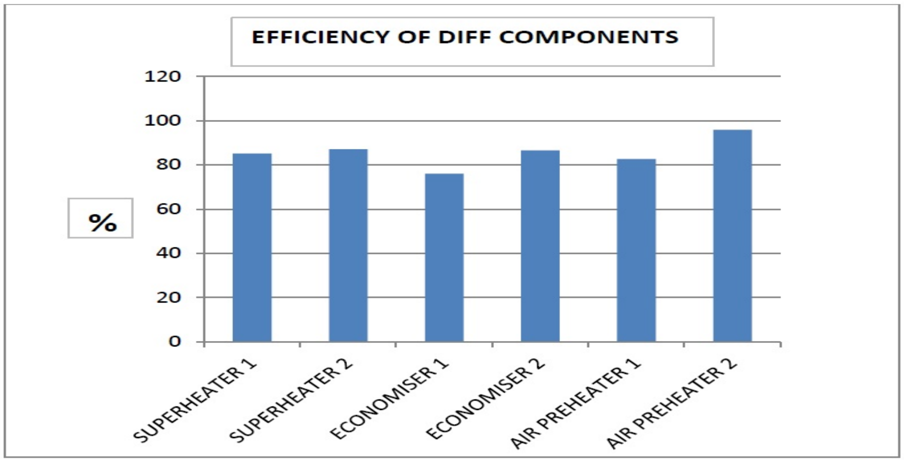

Figure 5.1: comparison of components of boiler with respect to thermal efficiency

5.2 EXERGY DESTRUCTION

Fig 5.2 explains the exergy destruction in various boiler components and it also shows that the largest amount of exergy destruction is compared to Super-heaters, the exergy destruction in other components is less.

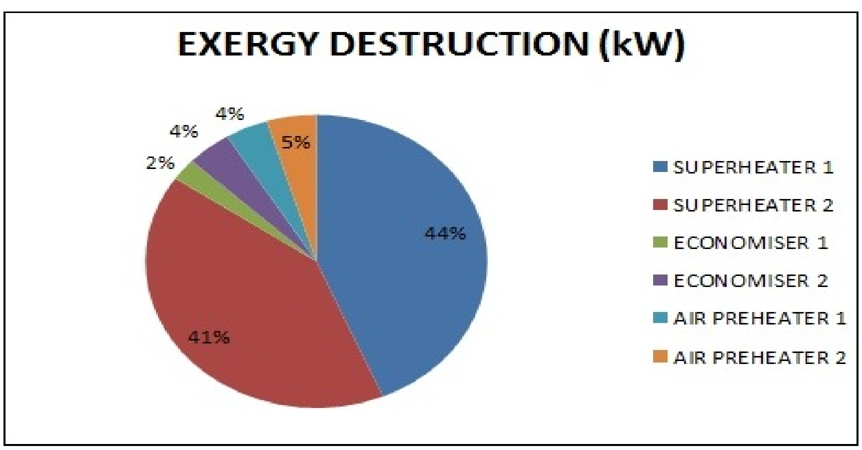

Figure 5.2: Exergy destruction for boiler components

Fig 5.3 explains the comparison of thermal efficiency and exergetic efficiency of boiler,turbine,condenser and cooling tower. Fig.5.3 helps to understand that exergetic efficiency is always less than thermal efficiency.

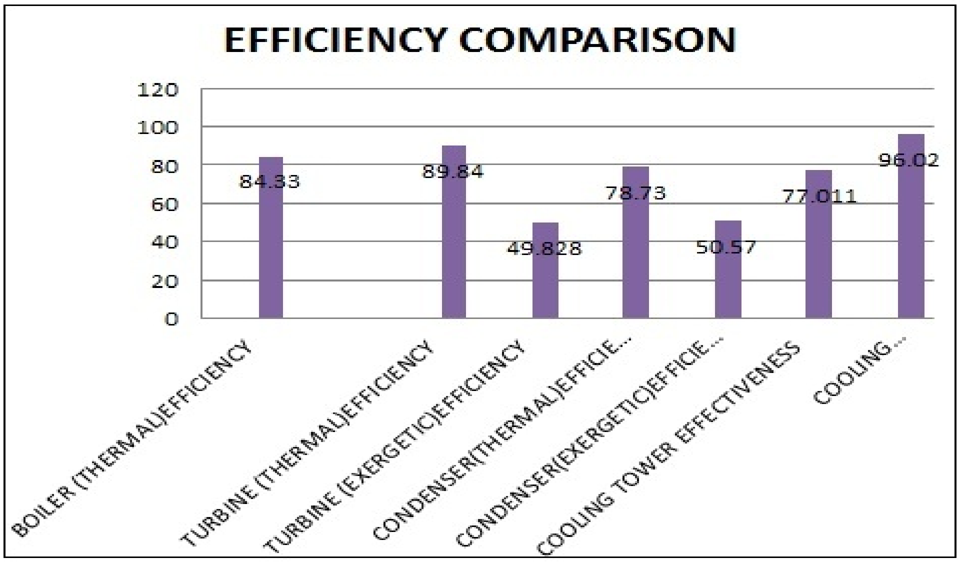

Figure 5.3: comparison of Thermal and Exergetic efficiency

5.3 SANKEY DIAGRAM

Sankey diagram is a specific type of flow diagram. In this diagram width of the arrows describe the flow quantity. Usually they are used to visualize energy or material or cost transfers between processes.

They are also used to get the idea about the energy accounts or material flow accounts on a regional or national level. Sankey diagrams also describes the major transfers or flows within a process. Sankey diagrams show conserved quantities within defined system boundaries. Mainly it indicates energy or mass, but they can also be used to show flows of non-conserved quantities such as exergy.

When energy is being used, Sankey Diagrams drops their arrows.

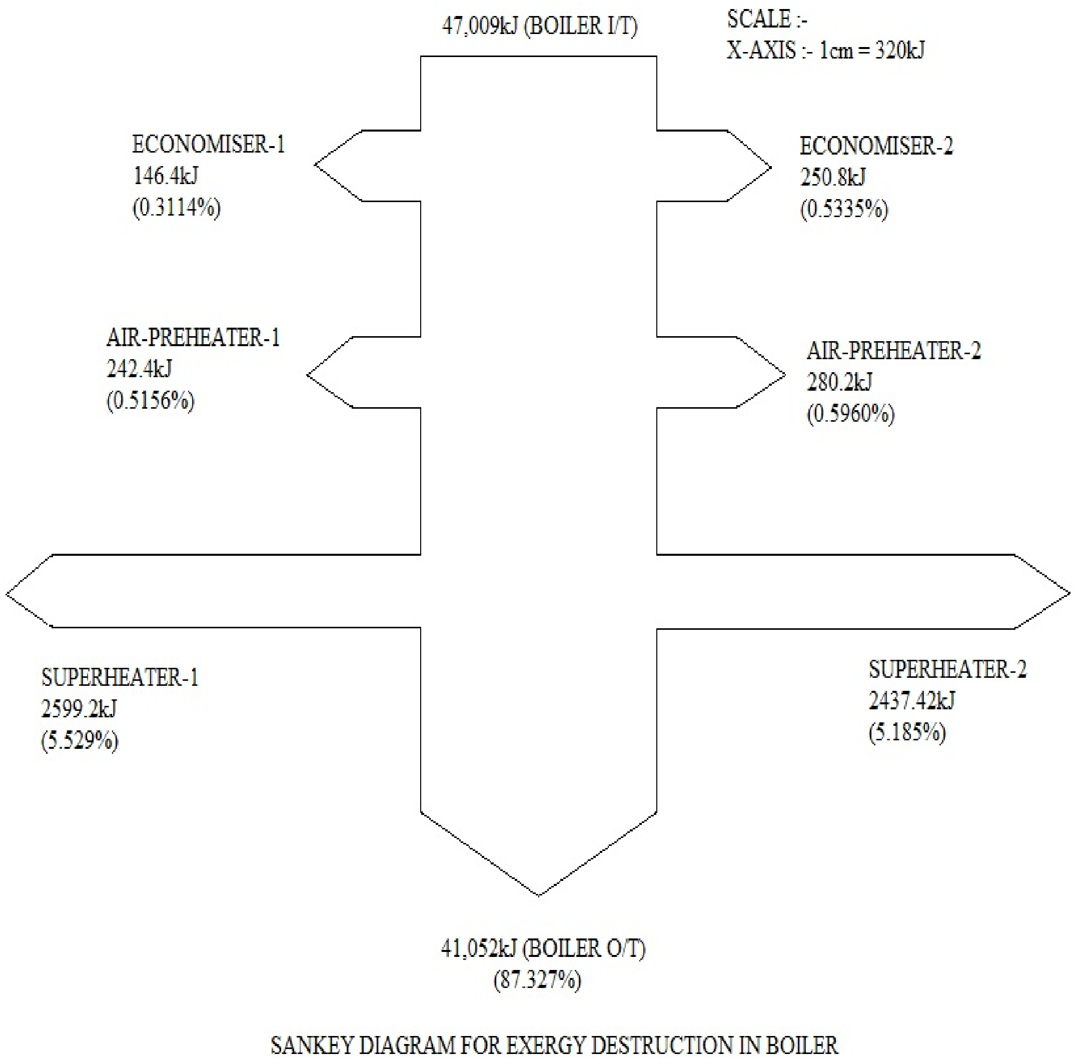

Figure 5.4: Sankey diagram for exergy loss(destruction) in Boiler

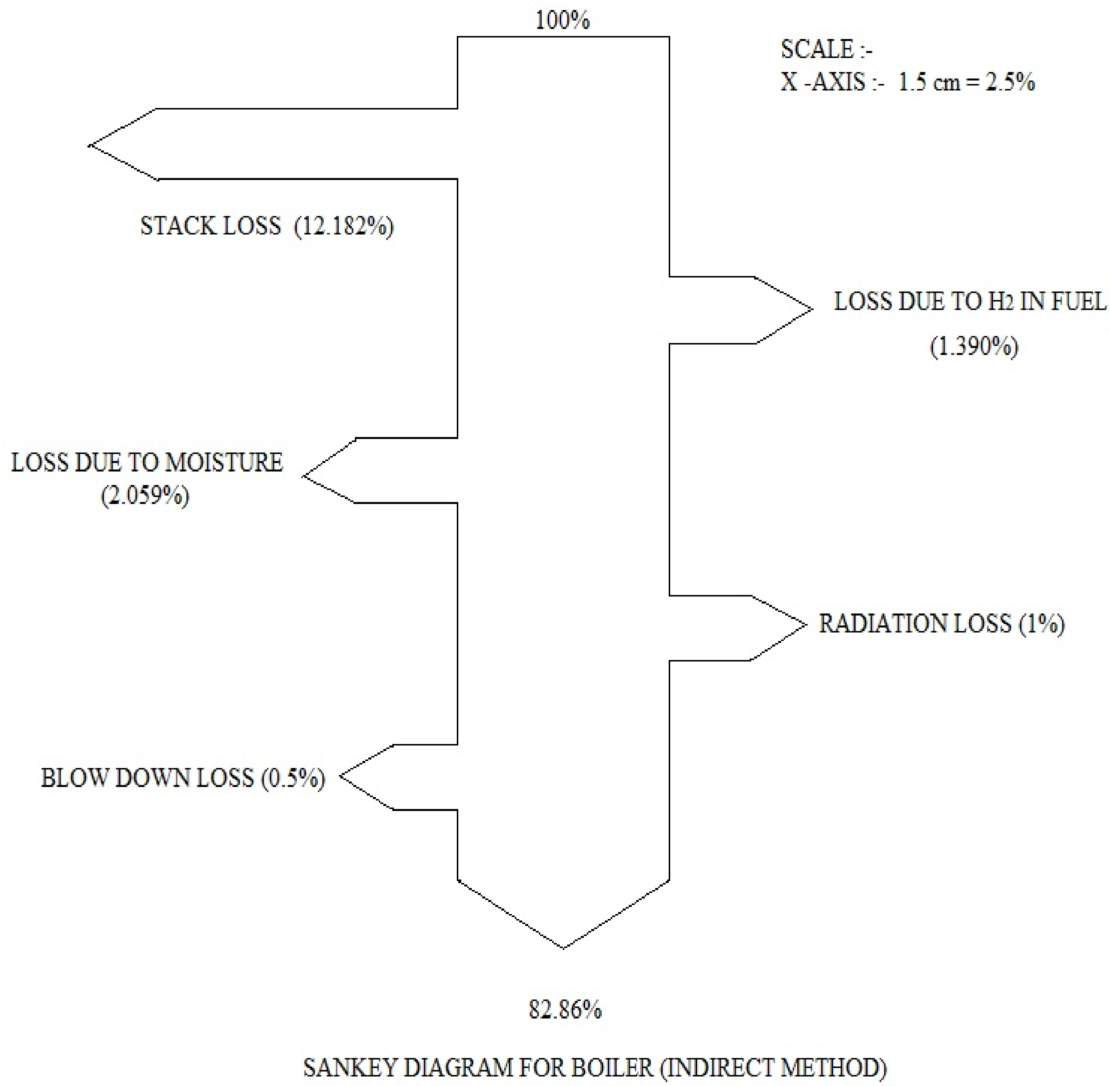

Figure 5.5: Sankey diagram for losses n boiler (Indirect method)

5.3.1 RESULTS AFTER IMPLEMENT

Fig 5.6 explains comparison of exergy destruction of various components of boiler before and after implementation of modifications suggested. It is observed that exergy destruction in super-heater has reduced from 2337.425 kW to 1895.77 kW, which will improve the boiler efficiency.

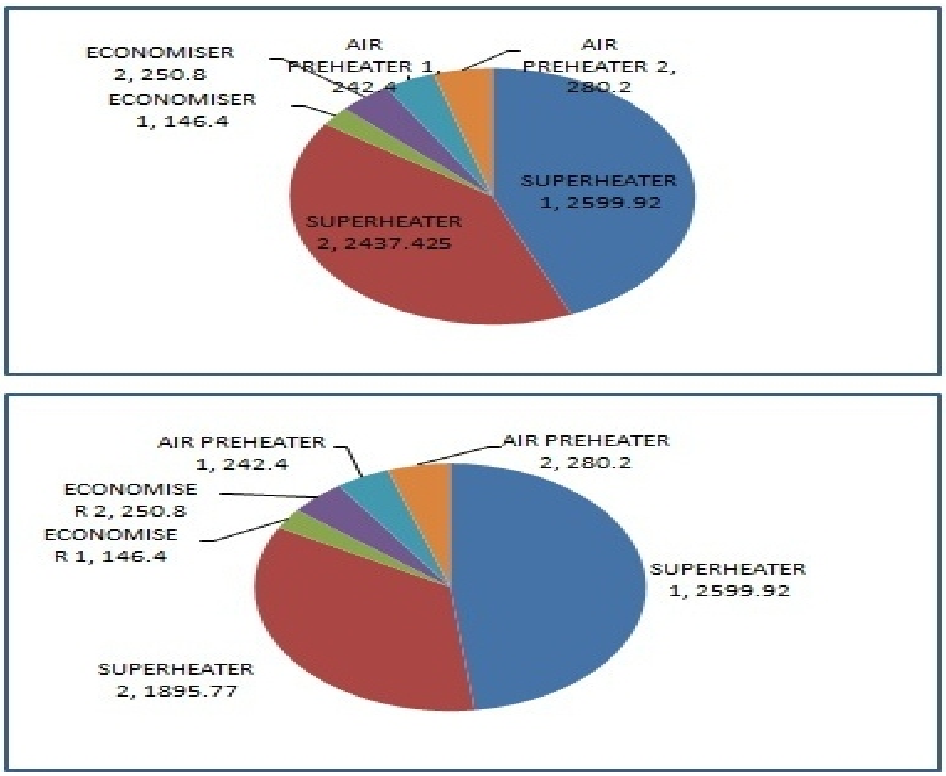

Figure 5.6: Comparison of exergy destruction(kW) for boiler

Total exergy destruction has been reduce from 2437.425 kW to 1895.77 kW in super-heater-2, which will help the boiler to improve it's performance.

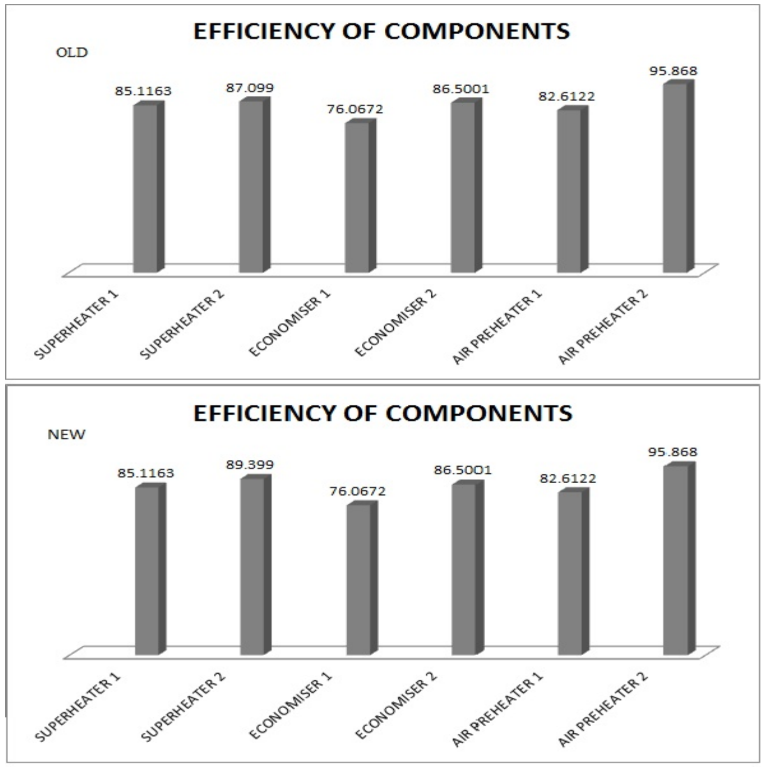

Figure 5.7: Comparison of efficiency of components

Fig 5.7 shows efficiency comparison for different components of boiler. Graph shows that in super-heater-2 , efficiency has increased from 87.09% to 89.399%, which in turn will increase boiler efficiency.

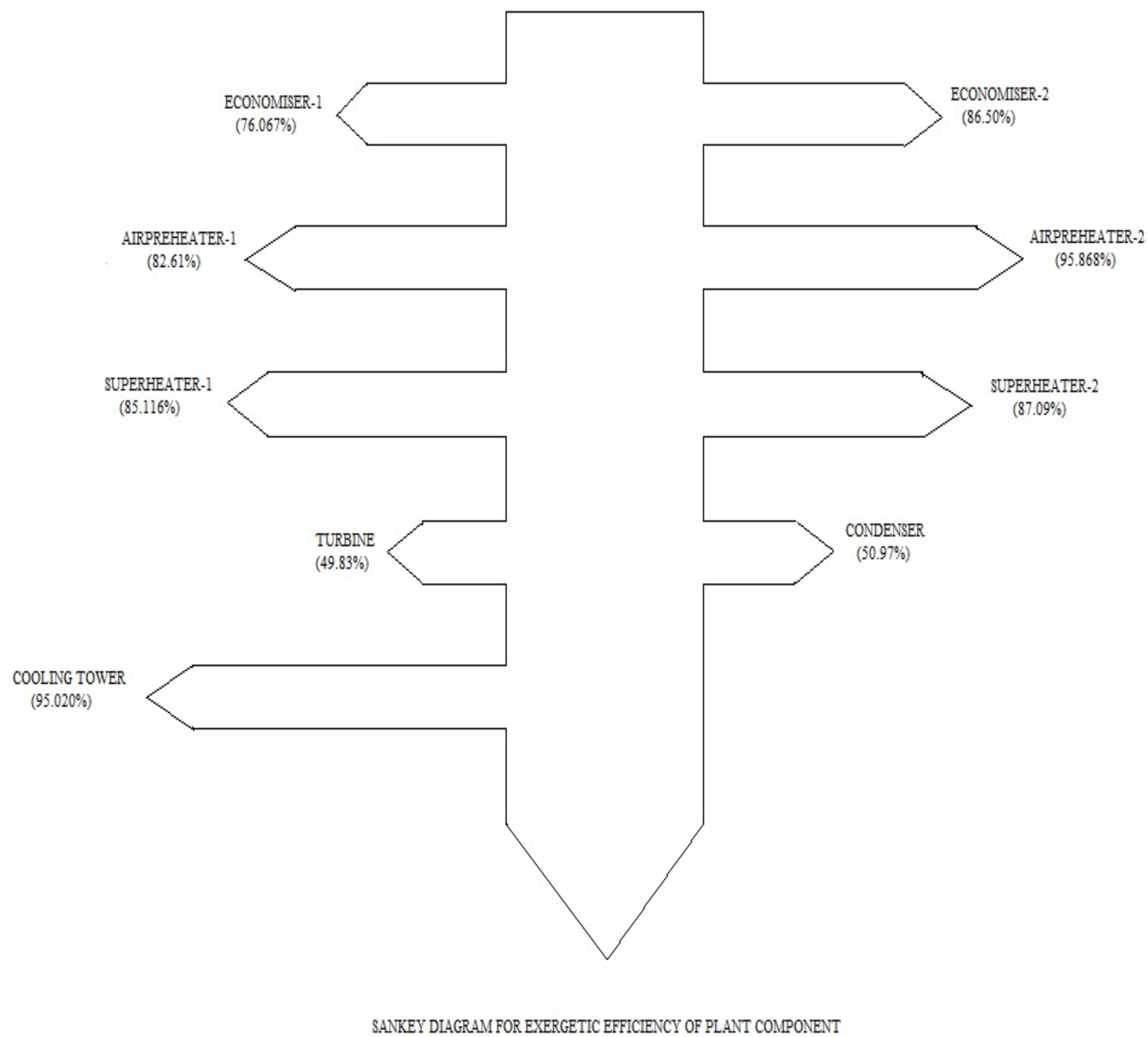

Figure 5.8: Sankey diagram for exergetic efficiency of plant components

Above sankey diagram is given to understand exergetic efficiency of different plant components. It shows which component has less performance or which component is required to be checked so it's performance is improved.

5.4 COST ANALYSIS

The approximate calculation is given below for cost analysis and required data for this calculation are given by company.

Steam generation for boiler = 60 TPH

Steam generation for one day = 60*24 = 1440 tonne /day

Cost of steam (given by industry) = Rs.850 / tonne

Old efficiency of super-heater = 87.099 %

New efficiency of super-heater = 89.399 %

Increase Increase in efficiency = 1.3 %

As efficiency increases its steam generation rate will increase, too. So, after implementation in super-heater, increase in steam generation is given as,

= (1440/130)

= 11.07 tonne per day

According to given cost of stem , the benefit in cost per day is,

= 850*11.0769

= Rs.9145.3

So, it is easy to understand from analysis that after getting more efficiency and less exergy destruction in super-heater affect the cost as shown in above.

Chapter 6

CONCLUSIONS AND FUTURE WORK

6.1 CONCLUSIONS

From the present analysis the following conclusions are drawn

- The Second law efficiency of power plant is always less than the first law efficiency because of the exergy factor being less than unity for process heat.
- The second law efficiency clearly indicates the destruction of exergy at various component of plant. Therefore to increase the second law efficiency of the plant attempt should be to reduce the destruction of exergy possible.
- After looking to the above graphs the one thing is very clear that the main reason for losses in power plant turbine and boiler. In boiler also maximum loss is occurring in Super-heaters. Air-pre-heaters and economizer's losses we can neglect because they are very small compare to Super-heaters.
- Turbine unit should be run at full load as far as possible for longer duration

for less exergy destruction. And efficiency will increase 2 to 3 %.

- By reducing excess air, Indirect Efficiency of boiler increase from 82.86 % to 83.87% by 1.01%

- Exergy destruction has been reduced from 2437.42 kW to 1895.77 kW in super-heater-2.Exegetic efficiency has also increased from 87.09 % to 88.39% by 1.3% in super-heater

6.2 FUTURE WORK

Thermodynamic and thermo economic optimization of plant for the following objective can be done in future.

- Turbine has exergy destruction 15,888 kW Condenser has exergy destruction 14,868 kW.So, there is possible work in turbine condenser to reduce destruction and increase performance.

- Minimization of the total irreversibility of the system

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APPENDICES

Table for boiler components and their efficiency

COMPONENTS	EFFICIENCY (%)
SUPERHEATER-1	85.1163
SUPERHEATER-2	87.099
ECONOMISER-1	76.0672
ECONOMISER-2	86.5001
AIRPREHEATER-1	82.6122
AIRPREHEATER-2	95.868

Table for boiler components and exergy destruction

COMPONENTS	EXERGY DESTRUCTION (kW)
SUPERHEATER-1	2599.92
SUPERHEATER-2	2437.425
ECONOMISER-1	146.6
ECONOMISER-2	250.8
AIRPREHEATER-1	242.4
AIRPREHEATER-2	280.2

Table for exergetic efficiency of plant components

COMPONENTS OF PLANT	EFFICIENCY
BOILER (THERMAL)EFFICIENCY	84.33
TURBINE (THERMAL)EFFICIENCY	89.84
TURBINE (EXERGETIC)EFFICIENCY	49.828
CONDENSER(THERMAL)EFFICIENCY	78.73
CONDENSER(EXERGETIC)EFFICIENY	50.57
CONDENSER(EXERGETIC)EFFICIENY	50.57
COOLING TOWER EFFECTIVENESS	96.02
COOLING TOWER(EXERGETIC)EFFICIENCY	96.02