© 2017 IJSRSET | Volume 3 | Issue 1 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology

# Energy and Exergy Analysis and Exergy Economics Analysis of Coal Based Thermal Power Plant

**Manoj Chourasiya[1], Suresh Kumar Badholiya[2]**
M.Tech Research Scholar's[1], Professor[2]
Bhopal Institute of Technology & Science, Bangrasia, Bhopal, Madhya Pradesh, India

## ABSTRACT

The energy assessment must be made through the energy quantity as well as the quality. But the usual energy analysis evaluates the energy generally on its quantity only. However, the exergy analysis assessment the energy on quality as well as the quantity. The aim of the exergy analysis is to identify the magnitudes and the real energy losses, in order to improve the existing systems, processes components The exergy losses occurred in the various subsystems of the plant and their components calculate using the mass, energy and exergy balance equations. The first (energy efficiency) and the second law efficiency (exergy efficiency) of the plant will be calculated. The real losses of energy which has a scope for the improvement are given as maximum exergy losses that occurred.
**Keywords :** Exergy Efficiency, FLT, CPF, Thermal Exergy, HPT, HP, LPH2, LPT, LPH1, EXP, HPH3, STPS, CERC

## I. INTRODUCTION

### 1.1 Energy and Exergy Analysis

Energy and exergy analysis for power generation systems are of scientific, interest and also essential for the efficient utilization of energy resources for this reason. The energy analysis has drawn much attention by scientific and system designers and recent year some Devoted their studies to component energy analysis and efficiency improvement.

Efficiency is one of the most frequently used terms in thermodynamics and it indicates how well and energy conversion or process is accomplished, efficiency is also one of the most frequently most used terms in thermodynamic and is often a source of misunderstanding this is because efficiency is often used without being properly defined first efficiency traditionally has been first law that is energy, in recent decades exergy analysis has been found increasingly wide spread acceptance as a useful tool in the design assessment optimization and improvement of exergy system.

Determining exergy efficiencies for an overall system and the individual component making up system constitutes a major part of exergy analysis. A part of exergy analysis. A comprehensive analysis of a thermodynamic system includes both energy and exergy analysis in order to obtain a more complete picture of system behaviour.

### 1.2 Energy

The industrial revolution is a result of the discovery of how to exploit energy and how to convert into work, nature allows the conversion of the work completely into heat, but heat is taxed when converted 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 maximum this return. Most of our daily activities energy transfer and energy change.

#### 1.2.1 Concept of Energy

The concept of the energy was first introduced in mechanics by Newton when he hypothesized about kinetic and potential energies. However, the emergence of energy as a unifying concept in physics was not adopted until the middle of 19$^{th}$ century and was considered one of the major scientific achievements in that century. The concept of energy is so familiar to us today that it is intuitively obvious, yet we have difficulty in defining it exactly .energy is scalar quantity that cannot be observed directly but can be recorded and evaluated by indirect measurement. The absolute value of energy of system is difficult to measure, whereas its energy is change rather easy to calculate. In our life the example of energy are endless. The sun of the major source of the Earths energy. It emits a spectrum of energy that travels across space as electromagnetic radiation. Energy is also associated with the structure of matter and can release by chemical and atomic reactor. Throughout history the emergence of civilization has been characterized by the discovery and effective application of energy to society's needs

### 1.2.2 Forms of Energy

Energy manifests itself in many forms, which either internal or transient, and energy can be converted from one form to another in thermodynamic analysis, the forms of energy classified into two groups.

(1) The macroscopic forms of energy are those where a system possesses as a hole with respect to some outside reference frame such as kinetic and potential energies. The macroscopic energy of a system is related to motion and the influence of some external effects such as gravity, magnetism, electricity and surface tension.
i.) The energy that a system possesses as a result of its motion relative to some reference frame is called kinetic energy.
ii). The energy that a system has a result of its elevation in gravitational field is called potential energy.

(2) The microscopic forms of energy are those related to molecular structure of a system and the degree of the molecular activity, and they are independent of outside reference frame. The sum of all the microscopic forms of energy is called the internal energy of a system. The internal energy of a system depends on the inherent qualities, or properties, of the materials in the system, such as composition and physical form as well as the environmental variable (temperature, pressure, electric field, magnetic field, etc.)

### 1.2.3 The First Law of Thermodynamics (FLT)

The first lows of thermodynamics stand for the first low of energy conservation of energy. This is stated as energy neither created or nor destroyed; it just change from. The FLT defines internal energy as a state function and provides a formal statement of the conservation of the energy. However, it provides no information about the direction in which processes can spontaneously occur, that the reversibility aspect of thermodynamic processes.

### 1.2.4 First Law of Thermodynamics Vs. Exergy

The total energy E represents the sum of all forms of energy a system possesses, and the change in the energy content of a system during a process is expressed as @system. In the absence of the electrical, magnetic, surface, etc. effects, the total energy in that case can be expressed as the sum of internal, kinetic, and potential energies as

$E=U+KE+PE$ and
$SYSTEM = \Delta U + \Delta KE + \Delta PE$

Energy can be transferred to or form a system in three forms: heat Q, work W, and mass flow m.

## 1.3 Exergy

The first law of thermodynamics, also known as the conservation of energy principle, provides a sound basis for studying the relationship among the various forms of energy interaction. Exergy analysis based on the second law of thermodynamics has added advantage.

Exergy is defined as the maximum work potential of a material or of forms of energy in relation to its environment. This work potential can be obtained by reversible process; however in reality there is only irreversible process happening. Unlike energy, the value of exergy depends on the state of the surrounding as well as the state the system .every substance not in equilibrium with its environments has some quantity of exergy, while a system that is in equilibrium with environment has, by definition zero exergy since it has no ability to do work with respect of its environment. The nature of exergy is opposite of entropy in that exergy can be destroy but it cannot be created. Entropy is the measure of molecular disorder or randomness of system, and the second law of thermodynamic state that the entropy can be created but it cannot be destroy.

In order to perform an exergy analysis first closed material and energy balance have to make. The greatest advantage of exergy calculations over energy calculations is that exergy calculations pin point exactly where the real losses in processes appear. Furthermore, the exergy content of a process is real valuation of exergy since it indicates the fraction of energy that really can be used. Exergy gives a major for the quality of energy. This applies on the process component level, the process level and the life cycle level.Energy and exergy analysis for power generation systems are of scientific, interest and also essential for the efficient utilization of energy resources for this reason. The energy analysis has drawn much attention by scientific and Energy. Frame such as kinetic and potential energies. The macroscopic energy of a system is related to motion and the influence of some external effects such as gravity, magnetism, electricity and surface tension.

## II. METHODS AND MATERIAL

### 1. Previous Work

In 1824 Carnot and clausius in 1965 proposed the fundamental of Exergy method. The exergy related systems are designed and their performance is evaluated primarily by using the energy balance deduced from the first law of thermodynamics and to calculate the enthalpy balances for more than a century to quantify the loss of efficiency in a process due to loss of energy. However in the recent year the second law of analysis here in after called exergy analysis, of energy systems has more and more drawn the interest of energy the exergy concept has gained considerable interest in the thermodynamic analysis of thermal process system .

**Szargu**t (1):A deeper analysis reveals that in real processes energy is not destroyed, but rather transformed into other forms, less suitable for feeding and driving real processes. Hence besides energy, another physical quantity should be introduced to characterize the quality of the kind of energy under consideration., Exergy analysis is based upon the second law of thermodynamics,

**T Ganapathy** (2): The energy assessment must be made through the energy quantity as well as the quality as well as the quality. The usual energy analysis evaluates energy generally on its quantity only.. The first law efficiency (energy efficiency) and the second law efficiency (exergy efficiency) of the plant have also calculated. The comparison between the energy losses and the exergy losses of the individual components of the plants shows that the maximum energy losses of 39% occurs in the condenser, whereas the maximum exergy losses of 42.73% occurs in the combustor. The real losses of energy which has a scope for the improvement are given as maximum exergy losses that occurred.

**Vundela sive Reddy** (3) He worked thermodynamic analysis of a coal based thermal plant and gas based cogeneration power plant has been carried out. The energy and exergy analysis has been studies for the different component of both power plants. The paper analysis the information available in the open literature regarding energy and exergy analysis on high temperature power plant has been included.

**Bejan (4):** He studied outlines the fundamentals of the method of exergy analysis and entropy generation minimization (or thermodynamic optimization the minimization of exergy destruction). The paper begins with a review of irreversibility, entropy generation, or exergy destruction. Example illustrate the accounting for exergy flows and accumulation in closed systems, open systems heat transfer processes, and power and refrigeration plant

**George and Park (5):** He worked how to estimate the avoidable and unavoidable exergy destruction and investment costs with compressors, turbines, heat exchangers and combustion chambers. This general procedure, although based on many subjective decisions, facilities and improves applications of exergy economics

**Kamateand Gangavati (6):**He studied exergy analysis of a heat-matched bio gas cogeneration plant of a typical 2500°c sugar factory, using back pressure and extraction condensing steam turbine is presented. The results show that, at optimal steam inlet condition of 61 bar and 475°c, the back pressure steam turbine cogeneration plant perform with energy and exergy efficiency of 0.863 and 0.307 and condensing steam turbine plant perform with energy and exergy efficiency of 0.68 and 0.260

**Dattaetal(7)** He was presented work on exergy analysis of a coal based thermal power plant is done using the design data from a 210 MW thermal power plant under operation in India. The exergy efficiency is calculated using the operating data from the plant art different conditions, viz. at different loads, different condenser pressures, with and without heaters and with different setting of the turbine governing load variation is studied with the data at 100, 75 ,60 and40 % of full load. Effects of two different condenser pressures, i.e76 and 89mmHg (abs.) are studied.

**Aljundi (8):** He was presented in this study, the energy and exergy analysis of AL-Hussein power plant Jordan is presented. 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. In addition, the effect of varying the reference environment state on this analysis will also be presented.

**Daietal (9) :** He was done exergy analysis for each cogeneration systems is examined, and a parameter optimization for each cogeneration system is achieved by means of genetic algorithm to reach the maximum exergy efficiency. The cement production is an energy intensive industry with energy typically accounting for 50-60% of the production costs.

**Rosen (10) :** He is reported results were of energy and exergy based comparisons of coal-fired and nuclear electrical generating stations. A version of a process-simulation computer code, previously enhanced by the author for exergy analysis, is used. Overall energy and exergy efficiencies, respectively, are 37% and 36% for the coal-fired process, and 30% and 30% for the nuclear process.

**Dincer and Rosen (11) :** He worked effects on the result of energy and exergy analyses of variations in dead-state properties, and involve two main tasks (1) examination of the sensitivities of energy and exergy values to the choice of the dead-state properties and (2) analysis of the sensitivities of the results of energy and exergy analyses of complex systems to choice of dead-state properties..

**Erdental (12) :** He analyzed comparatively the performance of nine thermal power plants under control governmental bodies in turkey, from energetic and energetic view point. The power plants are mostly conventional reheat steam power plant fed by law quality coal.

**Vidaletal (13)** : He analyzed exergy method was applied in order to evaluate the new combined cycle proposed by Goswami, using Hassan-Goswami-vijayaraghavan-parameters. This new combined cycle was proposed to produce both power and cooling simultaneously with only one heat source and using ammonia-water mixture as the working fluid.

**Amirabedin Ehsaan, M. Zeki Yilmazoglubfo (14) :** He worked to design a 240MWel thermal power plant (TPP) to be operated with ten different types of Turkish lignite and fulfill an exergy analysis including the determination and comparison of the performance reach type of lignite.with 299.10MW and 83.29% of the total exergy destruction of the overall plant point is that, fuel consumption and CO2 emission of the TTP increase with rising ambient temperature. I

## 2. Proposed Methodology : Exergy Analysis of Power Plant

### 2.1 Introduction

It is well known that the exergy can be used to determine the location, type and true magnitude of exergy loss (or destruction). Thus, it can play important role in developing strategies and in providing guidelines for more effective use of energy in the existing power plants. Moreover, another important issues for improving the existing system is the origin of the exergy loss. Hence, a clear picture, instead of only the magnitude of exergy loss in each section, is required. Therefore, the exergy analysis has been widely used for the evaluation of the thermal power plants.

### 2.2 Method

The three balance equations are applied to find work output, the heat added, the rate of exergy decreases, the rate of irreversibility, and the exergy and energy efficiencies. The balance equation are then written as fallow The mass balance equation: total mass balance input = total mass balance output

$$W+Q = \sum mi.\,(h_{out} - h_{in})$$

The energy balance equation:

$$E_{in} + E_Q = E_{out} + E_w + E_d + E_L$$

**Table 1.** Exergy function defined for different energy stream condition

| Description | Expression |
|---|---|
| For pure substance | $E = m(h-h_o)-T_o(s-s_o)$ |
| for solid fuel | $E = m[(LHV)\left(1.0438 + 0.013\frac{xH}{xC} + 0.1083\frac{xO}{xC} + 0.0549\frac{xN}{xC}\right) + 6740xS$ |
| for gas phase | $E = m[(h-h_o) - T_o(s-s_o) + \sum xk\, ek^{CH} + RT_o \sum xk\, lnx^n k]$ |

Where subscripts in and out refer to streams entering and leaving the control volume respectively

$$EQ = (1 - \frac{T_o}{T_i})Q_i$$

$$E_w = W$$

The exergy destruction, ED, and the exergy loss, EL, are, measure of the inefficiencies associated with the irreversible taking place in the k, th plant component. When single components of a thermal system are considered, the exergy losses are usually zero

$$E_L = 0$$

Exergy of a stream of matter can be divided into different components. In the absence of nuclear, magnetism, electricity, and surface tension effects, exergy is the sum of

$$E = E_{PH} + E_{KN} + E_{PT} + E_{CH}$$

Where $E_{PH}$, $E_{KN}$, $E_{PT}$, $E_{CH}$, are the physical exergy, potential exergy, and chemical exergy, respectively?

Since the changes in the kinetic and gravitational potential energies are considered to be neglecting in the present work, physical exergy, which is the sum of kinetic, potential, and thermal exergies, reduces to thermal exergy only. Thermal exergy is defined as the maximum amount of work that can be obtained when a stream of matter is brought from its initial state to the environmental (restricted) state while only exchanging heat with the thermal reservoir of the environment. Whereas chemical exergy is defined as the maximum amount of work which can be obtained when the stream of matter is brought from the environment (restricted dead) state to the total dead (unrestricted) state as a result of heat transfer and exchange of substance only with the environment.

### 2.3 Exergetic Efficiency

Different definitions are being used for exergy efficiency. Common for the all types efficiency is that they are valid for steady state processes, where the system boundaries

**Table 2.** Exergy Efficiency

| COMPONENT | EXERFY EFFICIENCY |
|---|---|
| Boiler | $E_{out} - \frac{E_{in}}{E_f}$ |
| Steam turbine | $W_T/(E_{in} - E_{out})$ |
| Pump | $(E_{out} - E_{in})/W_P$ |
| Heater | $E_{out}/E_{in}$ |
| Condenser | $E_{out}/E_{in}$ |

The present work, the exergy analysis of steam power plants, the exergy of steam is calculated at all states and the changes in the exergy are determined for each major component. The source of exergy destruction (or irreversibility) in the boiler and steam turbine is mainly combustion (chemical reaction) and thermal losses in the flow path, respectively. However, the exergy destruction in the heat exchangers of the systems, i.e. condenser, feed water heater, is due to large temperature difference between the hot and cold fluid. The exergy efficiency for each component.

### 2.4 Classification Of Power Plant Components

The power plant component shown in figure 7.1 (B) boiler, (HPT) High pressure turbine, (IPT) intermediate pressure turbine, (LPT) Low pressure turbine, (C) condenser, (LP) low pressure pump, (LPH2) low pressure heater2, (LPH1) low pressure heater 1, (D) deaerator, (HPH3) high pressure heater 3, (HPH2) high pressure heater 2, (HPH1) High pressure heater 1, (HP) high pressure pump, (EXP) expansion valve etc.

The exergy analysis has been carried out for each component in the subsystems, to evaluate the exergy losses in the individual component and then the analysis is performed on the overall individual subsystems, to find out the exergy losses each subsystems. Finally the exergy analysis for the overall plant has been carried out and the total plant exergy losses have been computed. The exergy and the exergy losses of the components of each system have been determined using their mass, energy and exergy balance equations. The exergy destruction for each component and subsystems are then compared and presented. The exergy efficiency have also been computed for the individual components as well as for overall plant.

### 2.4.1 Boiler

**Table 3.** Boiler Specification

| COMPONENT | BOILER |
|---|---|
| Type | Balanced draft dry bottom single drum natural Circulation boiler |
| Maximum working pressure | $158.2 kg/cm^2$ |
| Elevation | 52 meter |
| Drum length | 17.68 meter |
| Maximum metal temperature | 345°C |

The power plant component classified below.

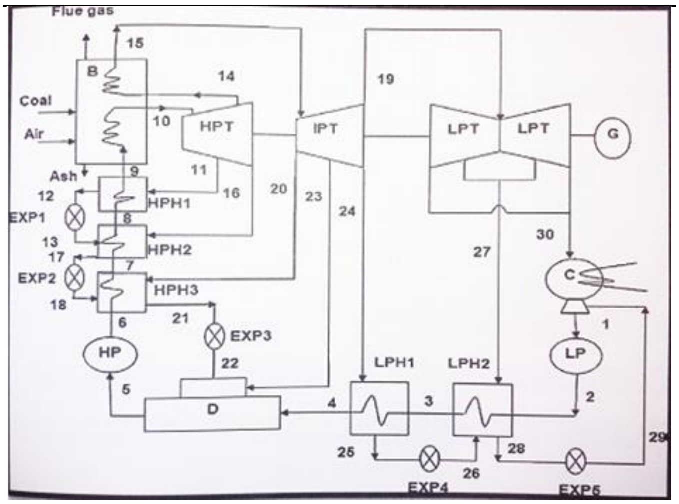


**Figure 1.** Power Plant Components

### 2.4.2 Condenser

**Table 3.** condenser specification

| COMPONENT | CONDENSER |
|---|---|
| Type | Double pass single shell |
| No. of tubes | 15620 |
| Condenser water flow | $27000 m^3/hr$ |
| Tube length | 9320mm |
| Condenser water velocity | 1.6m/sec |

### 2.4.3 Turbine

**Table 4.** Turbine Specification

| COMPONENT | TURBINE |
|---|---|
| Type | Condensing tendon compound three cylinder .Horizontally split disc & diaphragm type impulse turbine, nozzle governing and regenerative feed water heating double flow LP turbine |
| Rating | 200MW |
| rated speed | 3000rpm |
| Steam flow | 612 T/hr |
| Stages | HPT12,IP11,LP8 |
| Critical speed | 1585, 1881, 2017, 2489, 4508 |

### 2.4.4 Boiler Feed Pump

**Table 5.** Boiler Feed Pump Specification

| COMPONENT | BOILER FEED PUMP |
|---|---|
| Type | Weir pumps |
| Number of unit | 3 |
| Drive | Motor driven |
| Flow rate | 444T/hr. |
| Motor RPM | 1485 |

### 2.4.5 L. P. Heater 1:

**Table 6.** L.P heater 1 specification

| COMPONENT | L.P HEATER1 |
|---|---|
| Placement | Outside condenser |
| **Water** flow | 672 T/hr. |
| Steam flow | 8461kg/hr. |

#### 2.4.6 L. P. Heater 2:

**Table 7.** L.P heater 2 specification

| COMPONENT | L.P HEATER 2 |
|---|---|
| Placement | Inside condenser |
| **Water flow** | 672 T/hr. |
| Steam flow | 23533kg/hr. |

#### 2.4.7 Deaerator

**Table 8.** Deaerator specification

| COMPONENT | DEAERATOR |
|---|---|
| No. | One |
| **Type** | Spray |
| Storage capacity | 140m$^3$ |
| Location | 23m |

#### 2.4.8 HP Heater 1:

**Table 9.** HP heater 1 specification

| COMPONENT | HP HEATER 1 |
|---|---|
| Water flow | 672 T/hr. |
| **Temperature** inlet/ outlet | 166.76°C/187.29°C |
| Steam flow | 13515kg/hr. |

#### 2.4.9 HP Heater 2

**Table 10.** HP heater 2 specification

| COMPONENT | HP HEATER 2 |
|---|---|
| Water flow | 672 T/hr. |
| **Temperature** inlet/outlet | 187.29°C/224.75°C |
| **Steam flow** | 41949 kg/hr. |

#### 2.5. HP Heater 3:

**Table 11.** HP heater 3 specification

| COMPONENT | HP HEATER 3 |
|---|---|
| Water flow | 672 T/hr. |
| **Temperature** inlet/outlet | 224.75°C/248.75°C |
| **Steam flow** | 27940 kg/hr. |

#### 2.5.1 REHEATER

**Table 12.** Reheater specification

| COMPONENT | REHEATER |
|---|---|
| Reheater inlet no | 1+3 |
| **Pressure** | 142kg/cm$^2$ |
| **Reheater outlet no.** | 1 |
| Pressure | 30.58kg/cm$^2$ |

#### 2.5.2 GENERATOR

**Table 13.** Generator specification

| COMPONENT | GENERATOR |
|---|---|
| TYPE | Ac generator |
| **RPM** | 1500 |
| **Voltage** | 415 |
| Current | 434 AMP |
| Power factor | 0.8Lag |

## 3. Calculation Procedure

The data used in the analysis are obtained from actual operating data of the steam power plant of load 200MW the steam flow rate of turbine 170kg/s

**Table 14.** thermodynamics properties data

| Components | T°C | P bar | h KJ/kg | s KJ/kg | m kg/s |
|---|---|---|---|---|---|
| **HP** turbine Inlet | 536 | 127.79 | 3434.66 | 6.56925 | 170 |
| **HP** turbine outlet | 355 | 25.027 | 3058.67 | 6.7142 | 170 |
| Reheater Inlet | 355.4 | 25.027 | 3058.67 | 6.7142 | 170 |
| Reheater outlet | 536 | 22.326 | 3545.428 | 7.4765 | 148.06 |
| IP turbine Inlet | 536 | 22.326 | 3545.428 | 7.4765 | 148.06 |
| IP turbine Outlet | 343.654 | 4.402 | 3126.404 | 7.6344 | 148.06 |
| LP turbine Inlet | 343.654 | 4.402 | 3126.404 | 7.6344 | 126.12 |

| | | | | | |
|---|---|---|---|---|---|
| LP turbine Outlet | 194.827 | 1.073 | 2860.44 | 7.7955 | 126.12 |
| Condenser Inlet | 194.827 | 1.073 | 2860.44 | 7.7955 | 104.18 |
| Condenser outlet | 46.4 | 1.073 | 193.95 | 0.6586 | 104.18 |
| LP pump inlet | 46.4 | 1.073 | 193.95 | 0.6586 | 104.18 |
| LP pump outlet | 41.41 | 22.327 | 196.175 | 0.6586 | 104.18 |
| LP heater(2) Inlet | 41.41 | 22.327 | 196.175 | 0.6586 | 104.18 |
| LP heater(2) Outlet | 163.36 | 22.327 | 705.92 | 2.0062 | 126.12 |
| LP heater(1) Inlet | 163.36 | 22.327 | 705.92 | 2.0062 | 126.12 |
| LP heater(1) outlet | 195.36 | 22.327 | 838.505 | 2.2997 | 133.433 |
| Deaerator Inlet | 195.36 | 22.327 | 838.505 | 2.2997 | 133.433 |
| Deaerator Outlet | 218.05 | 22.327 | 934.52 | 2.4998 | 140.746 |
| HP heater inlet | 218.05 | 22.327 | 934.52 | 2.4998 | 140.746 |
| HP heater Outlet | 192.376 | 127.79 | 947.04 | 2.4628 | 140.746 |
| HP heater(3) Inlet | 192.376 | 127.79 | 947.04 | 2.4628 | 140.746 |
| HP heater(3)outlet | 218.12 | 127.79 | 1054.688 | 2.688 | 148.593 |
| HP heater(2) Inlet | 218.12 | 127.79 | 1054.688 | 2.688 | 148.593 |
| HP heater(2) outlet | 215.19 | 127.79 | 1192.92 | 2.9604 | 159.0293 |
| HP heater(1) Inlet | 215.19 | 127.19 | 1192.92 | 2.9604 | 159.029 |
| HP heater(1) outlet | 277.841 | 127.79 | 1304.32 | 3.1677 | 170 |

**(1) Exergy analysis for boiler**

Physical exergy for air = 0

Physical exergy for coal = 0

{Because of both are entering to the boiler at dead at dead state}

Exergy analysis for flue gas

Molecular weight of flue gas = 26.976

Mass flow rate = 7.2945

Stack temperature 150°C = 423K

**Table 15.** Enthalpy Calculation

| Constitute | Composition | Enthalpy |
|---|---|---|
| $Co_2$ | 0.09598 | -388305 |
| $H_2O$ | 0.09467 | -237557.28 |
| $SO_2$ | 0.0101 | -291307.6 |
| $O_2$ | 0.0429 | 3793.322 |
| $N_2$ | 0.7618 | 3735.41 |

Enthalpy of dry flue gas = $(0.0959 \times -388305.6) + (0.09467 \times -237557.28) + (0.0101 \times -291307.6) + (0.0429 \times 3793.322) + (0.7618 \times 3735.41)$

Enthalpy of dry flue gas = -61185.648KJ/K mole

**Table 16.** Entropy Calculation

| Constitute | Composition | Enthalpy |
|---|---|---|
| $Co_2$ | 0.09598 | 228.276 |
| $H_2O$ | 0.09467 | 202.035 |
| $SO_2$ | 0.0101 | 215.729 |
| $O_2$ | 0.0429 | 200.8 |
| $N_2$ | 0.7618 | 263.413 |

The values are at 1atm pressure we have to find entropy at 1.066 bars and at a temperature at 423K

$$S_{fg} = s°_{fg} - Rln(x \times \frac{p_{fg}}{p_{atm}})$$ ----------------------(1)

Where

$S°_{fg} = entropy\ at\ 1atm\ pressure$

$Rln = charecteristics\ gas\ constant$

$x = friction$

Putting these values in equation 1 we have:

**Table 17.** Entropy Calculation

| Constitute | **Entropy** | **Composition** |
|---|---|---|
| $S_{fg}so_2$ | 247.163 | 0.09985 |
| $S_{fg}H_2o$ | 220.137 | 0.09467 |
| $S_{fg}co_2$ | 241.64 | 0.0101 |
| $S_{fg}o_2$ | 204.026 | 0.0429 |
| $S_{fg}N_2$ | 301.349 | 0.7618 |

Entropy of flue gas= $(0.09985 \times 247.163) + (0.09467 \times -220.137) + (0.0101 \times 241.64) + (0.0429 \times 204.026) + (0.7618 \times 301.349)$
Entropy of flue gas = 214.359Kg/k mole-k

**Table 18.** Enthalpy Calculations

| **Constitute** | **Composition** | **Enthalpy** |
|---|---|---|
| $Co_2$ | 0.09598 | -393521 |
| $H_2O$ | 0.09467 | -285829 |
| $SO_2$ | 0.0101 | -296833 |
| $O_2$ | 0.0429 | 0 |
| $N_2$ | 0.7618 | 0 |

**Table 19.** Entropy Calculation at Dead State

| **Constitute** | **Composition** | **Enthalpy** |
|---|---|---|
| $Co_2$ | 0.09598 | 213.794 |
| $H_2O$ | 0.09467 | 69.948 |
| $SO_2$ | 0.0101 | 191.61 |
| $O_2$ | 0.0429 | 205.146 |
| $N_2$ | 0.7618 | 248.09 |

$$S_o = S° - Rln(x) \dots\dots\dots\dots\dots\dots\dots\dots \quad (2)$$

Where $S_o$ = entropy at dead state

$$S^o = absolute\ entropy$$

Putting these values in equation 2 we have:

| **Constitute** | **Composition** | **Enthalpy** |
|---|---|---|
| $S_0Co_2$ | 0.09598 | 232.95 |
| $S_0H_2O$ | 0.09467 | 89.547 |
| $S_0SO_2$ | 0.0101 | 193.872 |
| $S_0O_2$ | 0.0429 | 231.352 |
| $S_0N_2$ | 0.7618 | 286.298 |

Total entropy = 192.294 KJ/k mole-k

**Physical exergy of flue gas $E_{fg}$**

$$E_{fg} = \frac{m}{M}(h - h_o) - T_o(s - S_o)$$

=

$$\frac{7.2945}{26.975}(-61185.648 - 69350.516) - 298(214.359 - 192.294)$$

= 469.282KJ/kg

**Chemical exergy of flue gas {model 1}**

$$E_{fg} = [\sum xk \times e_k^{ch} + RT_o \sum xk \ln(xk)]$$

$$CO_2 = 0.09985 \times 14176 + 8.314 \times 298.15(0.09985)\ln(0.09985)$$

= 845.189

$$SO_2 = 0.0101 \times 301939 + 8.314 \times 298.15(0.0101)\ln(0.0101)$$

= 2934.5376

$$N_2 = 0.7618 \times 639 + 8.314 \times 298.15(0.7618)\ln(0.7618)$$

= -26.975376

$$O_2 = 0.0429 \times 3951 + 8.314 \times 298.15(0.0429)\ln(0.0429)$$

= -165.3585

$$H_2o = 0.09467 \times 8636 + 8.314 \times 298.15(0.0946)\ln(0.0946)$$

= 264.369

$$E_{fg}^{ch} = 3851.757 \times \frac{m}{M}$$

$$= 3851.757 \times \frac{7.2945}{26.976}$$

= 1040.5KW

Total exergy of flue gas = physical exergy + chemical exergy
= 469.283 + 1041.54
= 1510.822KW

**Exergy analysis of coal**

**Physical exergy = 0**

Because it is at dead state

**Table 20.** chemical exergy of coal

| **Constitute** | **Composition** |
|---|---|
| **C** | 0.324 |
| **$N_2$** | 0.0455 |

| | |
|---|---|
| $O_2$ | 0.0724 |
| S | 0.0044 |
| $H_2O$ | 0.056 |

$$E_{coal} = [\sum xk \times e_k^{ch} + RT_o \sum xk \ln(xk)]$$

C = 0.324×404589+298.15×8.314(0.324) ln(0.324)

= 13018.69

$$S = 0.0044 \times 589158 + 298.15 \times 8.314(0.0044)\ln(0.0044)$$

$$S = 2533.113$$

$$O_2 = 0.0724 \times 3951 + 298.15 \times 8.314(0.0724)\ln(0.0724)$$

$$O_2 = -185.145$$

$$N_2 = 0.0455 \times 235249 + 298.15 \times 8.314(0.0455)\ln(0.0455)$$

= 10355.315

$$H_2O = 0.056 \times 45 + 298.15 \times 8.134(0.056)\ln(0.056)$$

$$= -397.597$$

Chemical exergy of coal = 14287.375/0.7

$$= 203553.393 \times \frac{mass\ flow\ rate\ of\ coal}{mass\ of\ coal}$$

$$= 203553.393 \times \frac{29.167}{23.778}$$

**Exergy analysis of boiler**

Physical exergy of air = 0

Physical exergy of coal = 0

Total exergy of flue gas = 249683.487MW

**Reheater outlet**

h = 3545.428KJ/kg

s = 7.4765KJ/kg-k

Mass flow rate = 148.06 kg/s

**HP heater (1) outlet**

h = 1304.72KJ/kg

s = 3.1677KJ/kg-k

Mass flow rate = 170kg/s

$$Reheater\ outlet\ E_{RH} = m[(h - h_o) - T_o(s - s_o)]$$

$$= 148.06[(3545.428 - 104.8) - 298.15(7.4765 - 0.367)]$$

$$= 195576.9809KW$$

$$HP(1)heater\ outletE_{HP} = m[(h - h_o) - T_o(s - s_o)]$$

$$= 170[(1304.72 - 104.8) - 298.15(3.1677 - 0.367)]$$

$$= 62031.520KW$$

Exergy input of the boiler = exergy of coal + exergy of air + exergy of HP heater outlet

$$\sum E_{in}\ boiler = 249683.348 + 0 + 62031.520$$

$$= 311715MW$$

Exergy output of the boiler = exergy of flue gas + exergy of Reheater outlet

$$\sum E_{out} boiler = 1510.822 + 197047.4389$$

= 198558.26KW

Exergy destruction = exergy of fuel + $(\sum E_{in} - \sum E_{out})$

= 249683.348 + (311715 – 198558.26)

= 136526.608KW

$$\eta_{Boiler=} \frac{(\sum E_{in} - \sum E_{out})}{exergy\ fuel}$$

$$= \frac{311715 - 19858.26}{249683.608}$$

= 45.32%

**Table 21.** Exergy analysis of condenser

| Steam parameter | **Values** | **Water parameter** | **Values** |
|---|---|---|---|
| Enthalpy input | 2860.44KJ /kg | Enthalpy input | 146.7KJ/kg |
| Enthalpy output | 193.95KJ/kg | Enthalpy output | 168.8KJ/kg |
| Entropy input | 7.7955KJ/kg | Entropy input | 0.505KJ/kgK |
| Entropy output | 0.6586KJ/kg | Entropy output | 0.549KJ/Kgk |
| Mass flow input | 104.18kg/s | Mass flow input | 7500kg/s |
| Mass flow output | 104.18kg/s | Mass flow output | 7500kg/s |

Condenser input $E_{condenser} = m(h - h_o) - T_o\ (s - s_o)$

$$= 104.18(2860.44 - 104.8) - 298.15(7.7955 - 0.367)$$

= 56343.953KW

Condenser output $E_{condenser} = [m(h - h_o) - T_o\ (s - s_o)]$

$$= 104.18(193.95 - 104.8) - 298.15(0.6586 - 0.367)$$

= 230.18154KW

Condenser water input $E_{condenser} = m(h - h_o) - T_o\ (s - s_o)$

$= 7500[(146.7 - 104.8) - 298.15(0.505 - 0.367)]$
$= 5700KW$

Condenser water output $E_{condenser} = m(h - h_o) - T_o\ (s - s_o)$

$= 7500[(163.8 - 104.8) - 298.15(0.549 - 0.367)]$
$= 35550MW$

$$\sum E_{in}\ condensor = 56343.953 + 5700$$
$$= 62043.953KW$$

$$\sum E_{out}\ condensor = 230.18154 + 35550$$
$$= 35780.181KW$$

Exergy destruction =
$(\sum E_{in} condenser - \sum E_{out} condenser)$
= 62043.953-35780.181
= 26263.77KW

$$\eta_{condenser=\frac{\sum E_{out} condensor}{\sum E_{in} condenser}} = \frac{35780.181}{62043.953} = 57.6\%$$

**Table 21.** Exergy Analysis of HP Turbine

| **HP turbine** | **Values** |
|---|---|
| Enthalpy input | 3434.66KJ/kg |
| Enthalpy output | 3058.67KJ/kg |
| Entropy input | 6.56925KJ/kg |
| Entropy output | 6.71427KJ/kg |
| Mass flow rate input | 170kg/s |
| Mass flow rate output | 170kg/s |

HP turbine input $E_{turbine} = m[(h - h_o) - T_o\ (s - s_o)]$

$= 170[(3434.66 - 104.8) - 298.15(6.56925 - 0.367)]$
$= 251712.2KW$

HP turbine output $E_{turbine} = m[(h - h_o) - T_o\ (s - s_o)]$

$= 170[(3058.67 - 104.8) - 298.15(6.71427 - 0.367)]$
$= 180444.8kw$

$turbine\ work = m(h_{in} - h_{out})$
$= 170(3434.66 - 3058.67)$
$= 63918.3KW$

Exergy destruction = $(\sum E_{in} turbine - \sum E_{out} turbine)$ - turbine work
$= (251712.2 - 180444.8) - 63918.3$
$= 7349.1KW$

$$\eta_{turbine=\frac{turbine\ work}{\sum E_{in} condenser - \sum E_{out} turbine}} = \frac{63918.3}{(251712.2 - 180444.8)} = 89.68\%$$

**Table 22.** Exergy Analysis of Reheater

| **Reheater** | **Values** |
|---|---|
| Enthalpy input | 3058.67KJ/kg |
| Enthalpy output | 3545.428KJ/kg |
| Entropy input | 6.71427KJ/kgk |
| Entropy output | 7.4765KJ/kgk |
| Mass flow rate input | 170kg/s |
| Mass flow rate output | 148.06kg/s |

Reheater input $E_{Reheater} = m[(h - h_o) - T_o\ (s - s_o)]$
$= 170[(3058.67 - 104.8) - 298.15(6.71427 - 0.367)]$
$= 180444.8KW$

Reheater output $E_{Reheater} = m[(h - h_o) - T_o\ (s - s_o)]$
$= 148.06[(3545.428 - 104.8) - 298.15(7.4765 - 0.367)]$
$= 195578KW$

Exergy destruction =
$(\sum E_{in} Reheater - \sum E_{out} Reheater)$ - Q
$= (195578 - 180460.3464) - (4962.169)$
$= 10154.46KW$

$$\eta_{reheater=\frac{\sum E_{out} reheater}{\sum E_{in} reheater}} = \frac{175498.1774}{195578} = 89.7\%$$

**Table 23.** Exergy Analysis of IP Turbine

| **IP turbine parameter** | **Values** |
|---|---|
| Enthalpy input | 3545.428KJ/kg |
| Enthalpy output | 3126.404KJ/kg |
| Entropy input | 7.4765KJ/kgk |
| Entropy output | 7.6344KJ/kgk |
| Mass flow rate input | 148.06kg/s |
| Mass flow rate output | 148.06kg/s |

$IP\ turbine\ input\ E_{turbine} = m[(h - h_o) - T_o(s - s_o)]$
$= 148.06[(3545.428 - 104.8) - 298.15(7.4765 - 0.367)]$
$= 195578KW$

$$IP\ turbine\ output\ E_{turbine} = m[(h - h_o) - T_o(s - s_o)]$$
$$= 148.06[(3126.404 - 104.8) - 298.15(7.6344 - 0.367)]$$
$$= 126566.72MW$$
$$turbine\ work = m(h_{in} - h_{out})$$
$$= 148.06(3545.428 - 3126.404)$$
$$= 6970.59KW$$

Exergy destruction =
$$(\sum E_{in}\ turbine - \sum E_{out}\ turbine) - turbine\ work$$
$$= (195578 - 126566.72) - 62040.69$$
= 6970.59KW
$$\eta_{turbine} = \frac{turbine\ work}{(\sum E_{in}\ turbine - \sum E_{out}\ turbine)}$$
$$= \frac{62040.69}{(195578 - 126566.72)}$$
= 89.89%

**Table 24.** Exergy Analysis of LP Turbine

| **LP turbine parameter** | **Values** |
|---|---|
| Enthalpy input | 3126.404KJ/Kg |
| Enthalpy output | 2860.44KJ/Kg |
| Entropy input | 7.6344KJ/Kgk |
| Entropy output | 7.7955KJ/KgK |
| Mass flow rate input | 126.12kg/s |
| Mass flow rate input | 126.12kg/s |

$$LP\ turbine\ input\ E_{turbine} = m[(h - h_o) - T_o(s - s_o)]$$
$$= 126.12[(312.404 - 104.8) - 298.15(7.6344 - 0.367)]$$
$$= 106264.35KW$$
$$LP\ turbine\ output\ E_{turbine} = m[(h - h_o) - T_o(s - s_o)]$$
$$= 126.12[(2860.44 - 104.8) - 298.15(7.7955 - 0.367)]$$
$$= 67833.7965KW$$
$$turbine\ work = m(h_{in} - h_{out})$$
$$= 126.12(3126.404 - 2860.44)$$
$$= 33543.37KW$$

Exergy destruction =
$$(\sum E_{in}\ turbine - \sum E_{out}\ turbine) - turbine\ work$$
$$= (106264{,}35 - 67833.7965) - 33543.37$$
$$= 4887.183KW$$
$$\eta_{turbine} = \frac{turbine\ work}{(\sum E_{in}\ turbine - \sum E_{out}\ turbine)}$$
$$= \frac{38543.37}{(106264.35 - 67833.7965)}$$
$$= 88.67\%$$

**Table 25.** Exergy destroyed, exergy efficiency, exergy destruction ratio

| **Components** | **Exergy input MW** | **Exergy output MW** | **Exergy destroyed MW** | **Exergy efficiency%** | **Exergy destruction ratio%** |
|---|---|---|---|---|---|
| HP turbine | 251.7122 | 198.5582 | 7.3491 | 89.68 | 8.19 |
| IP turbine | 195.578 | 126.5667 | 6.97059 | 89.89 | 7.75 |
| LP turbine | 106.2643 | 67.833 | 33.543 | 88 | 38.11 |
| Condenser | 62.0439 | 35.7801 | 26.26377 | 57.6 | 45.59 |
| Feed pump | 25.848 | 24.945 | 0.894 | 76 | 1.18 |
| LP heater(1) | 157.0594 | 156.8675 | 0.192 | 60 | 0.32 |
| LP heater(2) | 194.84 | 194.605 | 0.245 | 76 | 0.34 |
| Deaerator | 197.37 | 197.113 | 0.257 | 85 | 0.302 |
| HP heater 3 | 248.812 | 192.189 | 56.623 | 77.24 | 73.307 |
| HP heater 2 | 336.274 | 292.223 | 44.051 | 86.90 | 50.691 |
| HP heater 1 | 672.218 | 624.634 | 47.5846 | 90.67 | 52.48 |
| Reheater | 195.578 | 180.4448 | 10.15446 | 89.7 | 11.324 |
| Boiler | 311.715 | 198.558 | 136.5266 | 45.32 | 301.250 |

## 4. Exergy Economics Analysis

### 4.1 Introduction

The technique of exergy of analysis develops for evaluation of the thermodynamics inefficiencies of systems exergy destruction and exergy. However often how much such inefficiencies cost will need to be known. Knowledge of these costs is very useful for improving the cost effectiveness of the system that is for reducing the cost of the final product produced by the system. The exergy analysis when combine with economics principal provide useful information for engineers or managers about their systems or plant performance

Cost accounting conventionally considers unit based on. However many researchers like have recommended that it will be better if cost accounting is based on exergy. One rational for this statement is that exergy is a consistent measure of economics value (that is often associated with a valuable commodity) while energy is only sometimes a consistent measure of economics value depending on the component.

This thesis presents the result of an exergy economics analysis performed on 200MW coal based steam power plant. All major components of the plant are considered in the cost of the exergy economics analysis. The exergy economics method for calculating the cost of the exergy per unit process flow stream.

**Step1:** in the thermodynamics analysis the detailed mass, energy and exergy balanced for the steam power plant are done. The mass, energy and exergy flow rates of all process stream are calculated with the aid of these detailed balanced. The exergy efficiency of each component is defined and calculated

**Table 26.** thermodynamics properties data

| **Components** | **T°C** | **P bar** | **h KJ/kg** | **s KJ/kg** | **m kg/s** | **Energy input MW** |
|---|---|---|---|---|---|---|
| **HP** turbine Inlet | 536 | 127.79 | 3434.60 | 6.56925 | 170 | 251.7122 |
| **HP** turbine outlet | 355 | 25.027 | 3058.67 | 6.7142 | 170 | 189.5582 |
| Reheater Inlet | 355.4 | 25.027 | 3058.67 | 6.7142 | 170 | 180.448 |
| Reheater outlet | 536 | 22.326 | 3545.428 | 7.4765 | 148.06 | 180.448 |
| IP turbine Inlet | 536 | 22.326 | 3545.428 | 7.4765 | 148.06 | 195.58 |
| IP turbine Outlet | 343.654 | 4.402 | 3126.404 | 7.6344 | 148.06 | 126.566 |
| LP turbine Inlet | 343.654 | 4.402 | 3126.404 | 7.6344 | 126.12 | 106.2643 |
| LP turbine Outlet | 194.827 | 1.073 | 2860.44 | 7.7955 | 126.12 | 67.833 |
| Condenser Inlet | 194.827 | 1.073 | 2860.44 | 7.7955 | 104.18 | 62.043 |
| Condenser outlet | 46.4 | 1.073 | 193.95 | 0.6586 | 104.18 | 26.26948 |
| LP pump in | 46.4 | 1.073 | 193.95 | 0.6586 | 104.18 | 25.848 |
| LP pump out | 41.41 | 22.327 | 196.175 | 0.6586 | 104.18 | 24.948 |
| LP heater(2) Inlet | 41.41 | 22.327 | 196.175 | 0.6586 | 104.18 | 194.84 |
| LP heater(2) Outlet | 163.36 | 22.327 | 705.92 | 2.0062 | 126.12 | 194.84 |
| LP heater(1) Inlet | 163.36 | 22.327 | 705.92 | 2.0062 | 126.12 | 157.0594 |
| LP heater(1) outlet | 195.36 | 22.327 | 838.505 | 2.2997 | 133.433 | 156.8675 |
| Deaerator Inlet | 195.36 | 22.327 | 838.505 | 2.2997 | 133.433 | 197.37 |
| Deaerator Outlet | 218.05 | 22.327 | 934.52 | 2.4998 | 140.746 | 197.113 |
| HP heater inlet | 218.05 | 22.327 | 934.52 | 2.4998 | 140.746 | --------- |
| HP heater Outlet | 192.376 | 127.79 | 947.04 | 2.4628 | 140.746 | --------- |
| HP heater(3) Inlet | 192.376 | 127.79 | 947.04 | 2.4628 | 140.746 | 248.812 |
| HP heater(3) outlet | 218.12 | 127.79 | 1054.688 | 2.688 | 148.593 | 192.189 |
| HP heater(2) Inlet | 218.12 | 127.79 | 1054.688 | 2.688 | 148.593 | 336.218 |
| HP heater(2) outlet | 215.19 | 127.79 | 1192.92 | 2.9604 | 159.0293 | 242.223 |

| | | | | | | |
|---|---|---|---|---|---|---|
| HP heater(1) Inlet | 215.19 | 127.19 | 1192.92 | 2.9604 | 159.029 | 672.218 |
| HP heater(1) outlet | 277.841 | 127.79 | 1304.32 | 3.1677 | 170 | 624.634 |

**Step 2:** As the second step, in the economics analysis the level zed investment and operating coast of each particular plat component are calculated. All cost due to owning and operating each particular plant component are calculated

- Return on equity
- Interest on loan capital
- Depreciation
- Interest on working capital
- Operation and maintenance expanses
- Cost of secondary fuel oil
- Compensatory allowance
- Special allowance in lieu of R&M

**Return on equity:** Debt: Equity for new projects- 70:30 or actual whichever is higher

- Existing projects- as already allowed by CERC during 2004-09
- Pre-tax return to incentivize investment in sector
- Rate of return will be 15.5% for existing station
- Pre-tax return of 15.5% will be post tax return of 23.481% for companies paying normal income tax

**Interest on loan capital:** Repayment equal to depreciation irrespective of actual repayment

- To be charged from 1st year of COD irrespective of moratorium
- @ Actual weighted average rate of interest at the beginning of each year
- If there is no actual loan available in any particular year, last available weighted average rate of interest shall be considered
- If there is no actual loan, then weighted average rate of interest of the company shall be considered
- Generator to attempt re-financing for benefit net benefit of refinancing to be shared in the ratio of 1 (gen): 2(beneficiaries)
- Refinancing cost is to borne by the beneficiaries

**Depreciation: depreciable value** 90% (except land);

- Depreciable life:
- Thermal- 25 years both coal and gas station
- Hydro-35 years
- As per companies Act for the 12 years after commercial operation and balance shall be spread over balance life

**Reason for increasing rate of depreciation**

- In India context, loans are available for a term of 10-15 years. In some rare cases long term loan is extended to 20 years.
- If loan is available for 12 years, annual repayment would be around 5.83% of the total investment taking into consideration 70% debt of the total investment. Whereas refund of capital in the form of depreciation is available to the context of 3.60% in case of thermal stations and which may be not sufficient to meet the loan repayment obligations without advances against depreciation.
- Therefore, providing higher rate depreciation in initial period of project will give some comfort to the investors towards repayment of their loan
- At the same time it will reduce the interest burden of the consumer and tariff will be reduced once the loan is repaid on account of reduced depreciation available over the balance useful life of the plant.

**Interest on working capital :** coal based stations

1. 1.5 months fuel expenses for pit head and 2 months for noon pit head
2. Secondary fuel oil for 2 months
3. Maintenance spares @ 20% of O&M
4. Receivable for 2 months
5. O&M 1 months

Rate of interest will be SBI PLR as on 1.4.2009 and no fuel escalation will be permitted in working capital

**Table 27.** interest on working capital

| Station | 08-09 Rs(cr) | 09-10(cr) | % increase | Increase(p/u) |
|---|---|---|---|---|
| Singrouli | 40 | 57 | 42.5 | 2.9 |

Operation & maintenance cost: expenditure incurred on the employees including gratuity, CPF, medical, education allowance, repair and maintenance expenses including stores and consumables, consumptions of capital spares which are not a part of capital cost, security expenses, administrative expenses etc. of the generating stations, corporate expenses apportioned to each generating stations others(water charge + insurance etc. )

**Methodology adopted by CERC while fixing O&M Norms**

- The actual O&M expenses of central utilities for the years 2004-2005 to 2007-2008 are taken.
- Then incentive % ex-gratia paid to its employees, donations, loss in stock, prior period adjustments, claims and advance are written off.

Then average norms have been calculated.

- Based on escalation rates for the year 2004-05 to 2007-08, the annual escalation rate worked out as 5.26%
- For arriving at base O&M cost at 2007-08 price level has been provided with 45% increase in employee cost in 2009-10

**Operation and maintenance expenses for 2009-10**
**Coal based stations : 2009**
**2010 in Rs Lac/MW**

200MW - 18.2 Lac/MW(12.17lac/MW)
300/330/350 - 16 lac/MW
500MW - 13 lac/MW(10.95lac/MW)
660MW - 11.7 lac/MW
TTPS - 32.75lac/MW (22lac/MW)
BTPS - 31.35 lac/MW (20.24lac/MW)

**Additional units which will be commissioned after 1.4.2009 in the same stations**

**200/210/250MW** (90%of above for unit 5 & 6, 85% of above for 7$^{th}$ onwards)
**300/330/350MW** (90%of above for unit 4 & 5, 85% of above for 6$^{th}$ onwards)
**500MW and above** (90%of above for unit 3 & 4, 85% of above for 5$^{th}$ onward)

**Table 28.** operation and maintenance expenses condition

| Station | For 08-09Rs. Cr | For 09-10Rs. Cr | % increase | Increase P/unit |
|---|---|---|---|---|
| Singrouli | 231 | 312 | 35.1 | 2.4 |

**Cost of secondary fuel oil:** reasons for shifting secondary oil cost to capacity charge

- Generator are scheduled to generate as per “merit-order” which means that when some generating stations or units have to backed down during off-peak hours, the generating stations/units of a higher variable costs should be given a decreased schedule while lower variable costs should continue with schedules matching their full available capacity
  - Therefore, energy charge rate for the different thermal stations should be as close as possible to the actual variable costs of the stations, for optimal operation of the whole system.
  - Secondary oil is required occasionally and at a load above about 70%, it is normally not required to be fired. Therefore, energy charge consisting of coal as well as oil charge does not give real situation on merit order.
  - Hence, oil is removed from energy charges and now it consist of only coal charges.

**Secondary fuel oil in AFC:**
As per 2004-09 regulation, secondary fuel oil was the component of variable charge. Now it is a component of fixed charge.

- Normative secondary fuel oil consumption up to target availability level will be a part of annual fixed charge

**For Example**

**Generation** of station at target plant availability (85%) = 48.0×365×0.85= 14892 Mu normative sec fuel oil consumption = 1.0×14892 KL
Price of this amount of oil will be a part of annual fixed cost.

- Landed cost of oil based on actual of the weighted average price of the preceding three months.
- Secondary fuel oil expenses will be subject to annual adjustment on annual basis based on the weighted average landed cost of oil
- Compensatory allowance: as per earlier regulation, generating companies were allowed to do work necessary for efficient operation of the plant and expenditure on these works become a part of capital cost (additional capitalization) subject to prudence check by CERC.

- But in this generation CERC has disallowed additional capitalization after cutoff date (except few cases)
- Therefore. CERC has provided following compensatory allowance for meeting small expenses which are capital in nature irrespective of actual expenditure.
- These expenses will be a part of fixed cost

**Table 29.** Compensatory Allowance

| Year of operation | **Comp. allowance(in Rs. lac/MW/yr)** |
|---|---|
| **0-10** | Nil |
| **11-15** | 0.15 |
| **16-20** | 0.35 |
| **21-25** | 0.65 |

**Renovation and modernization (R&M):**

**Issues**

Case: singrouli STPS

- Capital cost Rs 1181cr
- Depreciation recovered Rs 1005cr(Ex land cost)
- ROE allowed presently on Rs 582Cr @ 23.481%i.e, Rs 136.7Cr
- If NTPC wants to claim R&M for life extension, CERC will consider capital cost of singrouli as Rs 176Cr (1181Cr-1005Cr) which will reduce ROE to Rs 41.3Cr

**Income Tax:**

- income tax is not pass through
- tax holiday benefits will be retained with generator

**Income tax liabilities of NR stations:**

**Table 30.** income taxes

| **Stations** | Income tax(Cr) |
|---|---|
| Singrouli | **122.9** |

**Total impact cost:**

The total cost impact cost gain in fixed cost, gain in loss, total gain, Loss in energy. Loss in income (P/U) total loss impact (gain/loss)

**Table 31.** Total Impact Cost

| Total impact cost paisa/unit | **Singrouli** |
|---|---|
| Gain in fixed | 14.4 |
| Gain in loss | -0.3 |
| Total gain | 14.1 |
| Loss in energy | -8.4 |
| loss in income tax(P/U) | -8.4 |
| Total loss | -16.8 |
| Total impact(gain/loss) | -2.7 |

**Step 3:** A fuel and product for each process component are in accordance with the definitions of exergetic efficiency of each plant component. Fuel is the exergy, which derives the transformation undergone in the component. Product is the exergy value of the desired result in the same component. The fuel consist of all process flow stream the way they appears in the denominator (numerator) of the equation used for the calculation of exergetic efficiency

**Cost of exergy fuel = 1.5167 Rs/KWh**

**Step 4:** in this step cost exergy unit of each process flow streams is calculated

**Unit average cost define as**

$$K^* = \frac{E_o}{E_{in}}$$

$E_o$ = Exergy product
$E_{in}$ = Exergy fuel
{Reference: fundamental of exergy cost accounting,(**A. Valero, L.Serra, J.Uche**)}

**Table 32.** exergy destroyed, exergy efficiency, average cost

| **Component** | **Exergy input MW** | **Exergy output MW** | **Exergy Destroyed MW** | **Exergy Efficiency%** | **Exergy Average Cost** |
|---|---|---|---|---|---|
| **HP** turbine | 251.7122 | 198.5582 | 7.3491 | 89.68 | 0.7888 |
| IP turbine | 195.578 | 126.5667 | 6.97059 | 89.89 | 0.6471 |
| LP turbine | 106.2643 | 67.833 | 33.543 | 88 | 0.6383 |

| | | | | | |
|---|---|---|---|---|---|
| **Condenser** | 62.0439 | 35.7801 | 26.26377 | 57.6 | 0.5766 |
| **LP pump** | 25.848 | 24.945 | 0.894 | 76 | 0.9668 |
| **LP heater(1)** | 157.0594 | 156.8675 | 0.192 | 60 | 0.9987 |
| **LP heater(2)** | 194.84 | 194.605 | 0.245 | 76 | 0.9987 |
| **Deaerator** | 197.37 | 197.113 | 0.257 | 85 | 0.9986 |
| **HP heater(3)** | 248.812 | 192.189 | 56.623 | 77.24 | 0.7724 |
| **HP heater(2)** | 336.274 | 292.223 | 44.051 | 86.90 | 0.8690 |
| **HP heater(1)** | 672.218 | 624.634 | 47.5846 | 90.67 | 0.9292 |
| **Reheater** | 195.578 | 180.4448 | 10.15446 | 89.7 | 0.9226 |
| **Boiler** | 311.715 | 198.558 | 136.5266 | 45.32 | 0.7953 |

**Table 33.** Estimation of costs

| Cost | Rs/KWhr. | % |
|---|---|---|
| **Capital cost** | 0.06735 | 4.0489 |
| **Fuel cost** | 1.595 | 95.88 |
| **Operation & maintenance** | 0.00103 | 0.0619 |
| **Total** | 1.66338 | 100.00 |

## III. RESULTS AND DISCUSSION

### 1. Energy Analysis of Power Plant

**Table 34.** Result obtain from boiler and coal mills

| Description | Value |
|---|---|
| 1.stack loss | 5.136% |
| 2. loss due to $H_2O_{moisture} + H_2O_C$ | 7.17% |
| 3. unaccounted loss | 1.5% |
| 4. sensible heat loss | 0.136% |
| 5. unburnt fly ash | 0.361% |
| 6. sensible heat loss in ash | 0.497% |
| 7. loss due to bottom ash | 0.176% |
| 8.loss due to combustion | 0.104% |

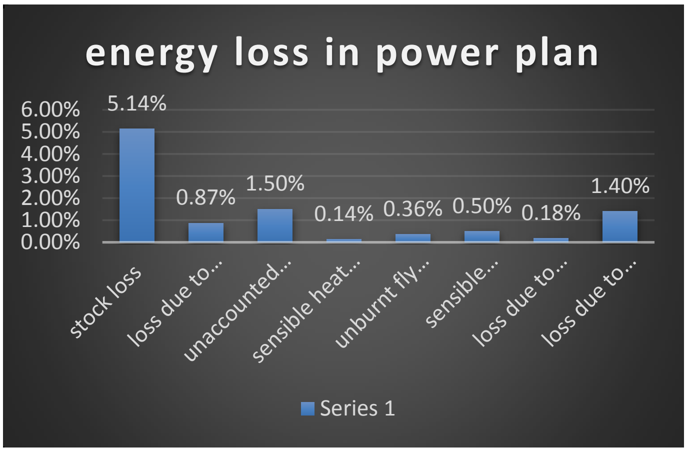


**Figure 2.** Losses in Boiler and Coal Mills

From the chart it is clear that losses energy losses due to the exhaust are more compared gas are to all boiler losses. From chart the stack loss is 5.173% and the loss due to moisture is 0.87% the lowest loss occurs due to ash 0.136% the all energy losses of boiler decreases the efficiency of boiler

**Table 35.** Different Efficiencies of Power Plant

| COMPONENTS | EFFICIENCY |
|---|---|
| **1. Boiler** | 84.12% |
| **2. Turbine** | 42.83% |
| **3. Generator** | 98% |
| **4. Overall efficiency** | 35.30% |

Super heater temperature 530°C and pressure 130kg/cm$^2$. That means that quality of steam is rich. Reheater temperature 530°C it is nearly super heater temperature 530°C so, we can say that reheater is good condition. Feed water temperature is 244.35°C. it is nearly 2500°C that is desirable. Due to turbine losses, we get turbine efficiency is very low which is 42.83% the efficiency of the turbine is determined estimating the net heat input to turbine and electrical power plant from the generator in terms of heat valves. Thus turbine efficiency obtained is 42.83%.the generator efficiency is taken as 98%. Than the overall efficiency is estimated as 35.30% it’s very low.

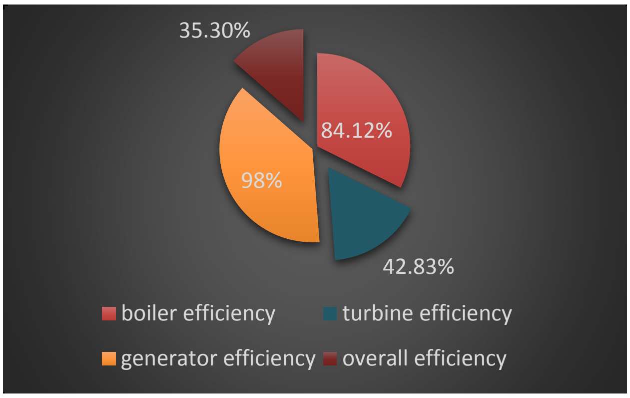


**Figure 3.** Comparison of Energy Efficiencies

From chart that the boiler efficiency is highest this is 84.12% only and the heat loss are only 15.88% out of the boiler heat losses is 7.17% occurs due to moisture and the turbine efficiency is 42.83% and the generator efficiency is taken as 98% from the thermodynamics analysis using the first law of thermodynamics we can conclude that energy analysis evaluate the plant quantitatively the power plant overall efficiency is 35.30%.

## 2. Exergy Analysis of Power Plant

The second law efficiency (exergy efficiency) of different component is also calculated and their comparison is depicted in figure it can be noted that the exergy efficiency of the HP turbine, I.P turbine, LP turbine, feed pump is 89.68%, 89.89%, 88%, and 76% respectively. The exergy efficiency of the boiler, condenser, and LP heater and HP heater are 45.32%, 57.60% and HP heater (1) is 89.70% respectively

**Discussion:**

It is apparent from the analysis of the total energy destruction occurs in the boiler this large exergy loss is mainly due to the combustion reaction and to the large temperature difference during heat transfer between the combustion gas and steam Obviously the lower superheated temperature 532° then the desired value of plant is maximum is on clear indication of the imperfection in the boiler comparing with exergy input to the plant this actually reduced the overall plant output other factor that may contribute to the high amount of irreversibility's are tube fouling defective burners, fuel quality insufficient soot blower, valves steam traps and air heater fouling Inspection of the equipment need to be carried out during the boiler outage the exergy loss in the turbines are due to the frictional effect and pressure drops across the turbine blades as well as the pressure and heat losses to the surrounding the high pressure(HP) intermediate (IP) and low pressure (LP) turbine constitutes a combined 47.89% of the total exergy destruction which indicates a need for reducing its irreversibility's. Other factor that may contributes to the irreversibility's are most likely due to the throttling losses at the turbine governor valves, silica deposited at the nozzle and blades and operating lower steam temperature then the recommended value. Amongst the three turbine the LP turbine produces the highest exergy destruction. Overheating the turbine may be needed to check the real causes for improving plant performance.

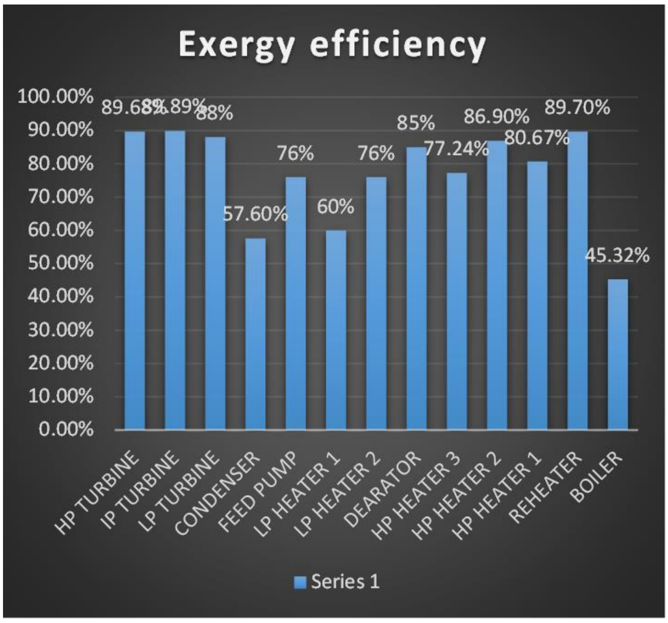


**Figure 4.** Exergy Efficiency

The exergy losses in the feed water heaters, from the thermodynamics point view are due to the finite temperature difference between the stream, which interchange heat, heat loss to the atmosphere and also due to the pressure drop. Amongst the feed water heaters, the high pressure (HP) 3 shows much higher losses as compared to the other heaters. Tubes inspection should be recommended during plant outage to determine the real cause. Other cause high irreversibility's are probably due to high percentage of plugged tubes, wrong venting operation poor maintenance and wrong water level

It is important to note that the above plant was built in 1983 the boiler design rated steam generating capacity 170kg/s and at temperature of 534°C before the throttling valve to the HP turbine, and the design reheated steam condition at the reheater stop valve before IP turbine 343.654°C of temperature and pressure 4.202 bars. Operating the plant below the rated output may be one of the main reasons for the reduced the plant performance. However the analysis above has identified the components that produce high exergy destruction.

### 3. Exergy Economics Analysis

**Discussion:**

The exergy unit cost for each material and energy flow stream is calculated based on certain assumption that no fuel costs are added to the condenser. For all other component the produced electric power is directly charged with the sum of the cost rate due to operation and maintenance, and the difference between the costs rates of fuel. The estimations of cost shown in table details calculations of each component can be obtained from thesis. The result obtained for cost per exergy unit shown in table

From the exergy economics analysis conclusions are made on the state of each component and recommendation made are listed below.

**Table 36.** Exergy Economics Analysis

| COMPONENTS | RECOMMENDATIONS |
|---|---|
| HP turbine | **No modification needed** |
| IP turbine | Improve component efficiency |
| LP turbine | Improve component efficiency |
| Condenser | Improve component efficiency |
| LP pump | **No modification needed** |
| LP heater(1) | Improve component efficiency |
| LP heater(2) | **No modification needed** |
| Dearetor | **No modification needed** |
| HP heater (1) | Improve component efficiency |
| HP heater (2) | **No modification needed** |
| HP heater (3) | **No modification needed** |
| Reheater | **No modification needed** |
| Boiler | Improve component efficiency |

## IV. CONCLUSION

### 1. Energy Analysis

From the energy analysis made for the 200MW unit of NTPC the following conclusion are draw:

- ✓ It is seen that the boiler efficiency is highest which is 84.12% and the loss are only 15.88%.
- ✓ Out of the all boiler losses the highest heat loss 7.17% occurs due to moisture.
- ✓ The turbine efficiency is very less and is estimated as 42.85% because of the several turbine losses like losses in regulating valve, nozzle friction losses, bled friction loss, disc friction losses, partial friction losses, carry over losses
- ✓ From the thermodynamics analysis using the first law of thermodynamics we can conclude that the energy analysis evaluates the plant quantitatively the power plant overall efficiency is 35.30%

### 2. Exergy Analysis

This present the result of exergy analysis performed on a 200MW coal based thermal power plant. The analysis are applied on the unit with running load 200MW exergy destruction on plant components are also presented and discussed and the possible causes of losses are identified. The result of the exergy indicates that the boiler produced the highest exergy destruction of 136.5266MW comparing three stages, the result of analysis indicates that the high pressure (HP) and intermediate pressure (IP) turbine produces exergy destruction and the low pressure turbine produced higher destruction comparing the result of the analysis on feed water heaters the high pressure heater 3 seems produce the highest exergy destruction.

### 3. Exergy Economics Analysis

This thesis is present a method of exergy economics analysis and its application to a power. An exergy analysis identifies the location, cause and magnitudes of the real thermodynamics losses. An exergy economics evaluation identifies the location and cause of the cost sources, calculates their magnitude and compares their effects on the cost of the product. All this information and judgment assist in the improvement of the efficiency and reduction of the costs in thermal power systems. Decisions about the design. Operation and repair or replacement of the equipment is facilitated.

## 4. Scope of The Present Work

The scope of present work includes the study of energy and exergy analysis exergy economics analysis of coal based thermal power plant. It includes experimental study of energy and exergy analysis and exergy economic analysis of coal based thermal power plant. Finally comparative assessment of experimental and numerical results is presented.

## V. REFERENCES


[1]. Hasan HE, Ali VA, Burhanettin, Ahmet D, Suleymen HS, Bahri S, Ismail T, Cengiz G, Selcuk A. Comparative energetic and exergetic performance analyses for coal-fired thermal power plants in Turkey. International Journal of thermal sciences 2009; 48:2179-86.

[2]. Aljundi Islam H. energy and exergy analysis of steam power plant in Jordan. Applied thermal engineering 2009; 29:324-8.

[3]. Datta A, Sengupta S, Dattagupta S. exergy analysis of coal based 210MW thermal power plant. International journal of energy research 2007; 31:14-28.

[4]. Naterer GF, Regulangada P, dincer I. exergy analysis of thermal power plant with measured boiler and turbine losses. Applied thermal engineering 2010; 30:970-6.

[5]. Rosen MA. Energy and exergy based comparison of coal-fired and nuclear steam power plants. International journal of exergy 2001; 3:180-92.

[6]. Ganapathy T, Alagumurthi N, Gakkhar RP, Murugesan K. exergy analysis of operating lignite fired thermal power plants. Journal of engineering science and technology Review 2009; 2:123-30.

[7]. Zubair SM, Habib MA. Second-law-based thermodynamic analysis of regenerative-reheat Rankine-cycle power plants. Energy 1992; 17:295-301.

[8]. Reddy BV, Butecher CJ. Second law analysis of a waste heat recovery based power generation systems. International journal of heat and mass transfer 2007; 50:2355-63

[9]. Suresh MVJJ, Reddy KS, Ajit KK. Energy and exergy analysis of thermal powr plants based on advanced steam parameters. In: national conference on advance in energy research. India: IITB; 2006

[10]. Oktay Z. investigation of coal-fired power plants in Turkey and s case study: can be plant. Applied thermal engineering 2009; 29:550-7.

[11]. Reddy BV, Mohamed K. exergy analysis of natural gas fired combined cycle power generation unit. International journal of exergy 2007; 4:180-96.

[12]. Srinivas T, Gupta AVSSKS, Reddy BV. Performance simulation f 210MW natural gas fired combined cycle power plant. International journal of energy, heat and mass transfer 2007; 29:61-82.

[13]. Can Gulen S, Smith WSR. Second law efficiency of the rankine bottoming cycle of a combined cycle power plant. International journal of engineering for Gas turbine and power 2010; 132:1-10.

[14]. Datta A, Ganguly R, Sarkar L. energy and exergy analyses of an externally fired gas turbine (EFGT) cycle integrated with biomass gasifier for distributed power generation. Energy 2010; 35:341-50.